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Studies of Larval Fishes in the Western and
Central Basins of Lake Erie

Ohio State Univ., Columbus

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DISTRIBUTION, ABUNDANCE
AND ENTRAINMENT STUDIES
OF LARVAL FISHES IN THE
WESTERN AND CENTRAL BASINS
OF LAKE ERIE

Prepared by

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16. ABSTRACT To assess the impact of entrainment of larval fishes at steam generating electrical power plants, samples were collected in Lake Erie. In 1975, 1976 and 1977 the Western Basin was sampled and in 1978 the sampling was concentrated in the Central Basin. In 1975 and 1976, waters offshore of Ohio and Ontario were sampled and 19 species of larval fish were obtained by using metered plankton nets. Yellow perch analysis indicates that shallow inshore waters serve as important nursery areas. Relict breeding populations of lake whitefish and sculpin were discovered. The 1975, 1976 sampling permitted calculation of an estimated impact of entrainment of adult yellow perch and emerald shiners using the adult approach. In 1975, 1976 and 1977, 98% of the 17 species found in the Maumee River estuary were gizzard shad/alewife, white bass/white perch and freshwater drum. These species made up 91% of the 11 species collected from the Sandusky River estuary. In 1977 gizzard shad/alewife, emerald shiners, white bass/white perch and yellow perch made up over 97% of the larval fish collected in Ohio and Michigan waters. Significantly more gizzard shad/alewife and spottail shiner were caught nearshore than at 5 meters deep offshore whereas more smelt were captured farther offshore than nearshore. More walleye were found on the Ohio shoreline than in Maumee Bay or along the Michigan shoreline, and more freshwater drum were collected in Maumee Bay. In 1978, 25 species were collected from the Central Basin in Ohio waters of which 82.4% were gizzard shad/alewives, emerald and spottail shiners. More gizzard shad, carp/goldfish, spottail shiners, trout perch and yellow perch were found in shallow (1-2 m deep) nearshore areas than in offshore deeper (5-10 m deep) areas. Field collections yielded higher estimates of entrainment than in-plant collections and significant differences were found between entrainment estimates from field samples and from in-plant samples from the Central Basin for gizzard shad, rainbow smelt, carp and freshwater drum.		
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ABSTRACT

As part of a multi-agency effort to assess the impact of entrainment of larval fishes at steam-generating electrical power plants, personnel from The Ohio State University collected samples of larval fishes from waters of the Western and Central Basins of Lake Erie. Samples were collected in the Western Basin in 1975, 1976 and 1977. Samples were collected along the southshore of the Central Basin in 1978.

A total of 19 taxa of larval fish was collected with metered plankton nets in Ohio and adjacent Ontario waters of the Western Basin of Lake Erie in 1975 and 1976. Analysis of yellow perch collections indicates that shallow inshore areas serve as important nursery areas for this species. Collection of larvae provides evidence of relict breeding populations of lake whitefish and sculpin in the Western Basin. Sufficient data was gathered from 1975 and 1976 collections to permit calculation of an estimate of the impact of entrainment on adult yellow perch and emerald shiner populations using the equivalent adult approach of Goodyear.

A total of 17 taxa were collected in the Maumee River estuary during sampling periods in 1975, 1976 and 1977. A total of 11 taxa were collected from the Sandusky River estuary in 1976. Gizzard shad/alewife, white bass/white perch and freshwater drum constituted 98 percent of the larvae collected in the Maumee River estuary proper and 91 percent of the larvae collected in the Sandusky River estuary.

Gizzard shad/alewife, emerald shiners, white bass/white perch, and yellow perch, constituted over 97 percent of the larval fish collected in Ohio and Michigan waters of the Western Basin of Lake Erie in 1977. Significantly greater numbers of gizzard shad/alewife and spottail shiner larvae were captured immediately adjacent to the shore than at a depth of five meters offshore while greater numbers of smelt larvae were captured at points further offshore at a depth of five meters than at points immediately adjacent to the shore. Significantly greater numbers of walleye larvae were collected along the Ohio shoreline portion of the study area than in Maumee Bay or along the Michigan shoreline. Significantly greater numbers of freshwater drum larvae were collected in Maumee Bay.

A total of 25 taxa of larval fish was collected in Ohio waters of the Central Basin portion of Lake Erie in 1978. Gizzard shad/alewives, emerald shiners and spottail shiners constituted 82.4 percent of the larval fish collected. Larval gizzard shad, carp/goldfish, spottail shiners, troutperch and yellow perch densities were significantly higher in shallow (1-2 m deep) nearshore areas than offshore in areas five and ten meters deep. Significant differences were found between entrainment estimates derived from field samples and in-plant samples from the Central Basin for gizzard shad, rainbow smelt, carp and freshwater drum. All estimates of entrainment from field collections were higher than those for in-plant collections.

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SECTION 1

INTRODUCTION

The Great Lakes provide a freshwater supply for 70 to 75 percent of the basin's 29 million residents (Great Lakes Communicator, 1979), increasingly attractive recreational boating and sport fishing areas, and water for industrial processes and electrical generation. Concern over the impacts of these conflicting uses has changed the prospective of this being an inexhaustible resource. The purpose of this report is to summarize a series of studies conducted to assess the abundance, distribution and entrainment of larval fishes in the Ohio and Michigan waters of Lake Erie. The study area serves as one of the best examples in the Great Lakes of divergent interests competing for a single resource. The impact of electrical generating facilities on larval fish numbers is potentially large. Electrical generation is the largest user of Great Lakes water. The 89 electrical generating stations in the coastal areas of the Great Lakes are responsible for over 70 percent of the total water use in the Great Lakes Basin (Murray and Reeves, 1977; Kelso and Milburn, 1979). With the United States relying more heavily on domestic energy supplies, the role of the Great Lakes will become even more important in energy production; it is planned that there will be an additional 17 power plants in the basin by the mid-1980's (Kelso and Milburn, 1979).

Thermal electric generating stations convert water into high pressure steam which powers electric generators. Little difference exists between fossil fuel and nuclear generating systems other than the type of fuel used to create high pressure steam. However, neither system uses all of the energy available for converting heat to electricity. The steam used to generate electricity must be condensed before re-heating for maximum efficiency. This is where the large water requirements and the environmental concerns arise (Kelso and Milburn, 1979).

Steam electric generating plants have three major types of adverse effects upon the aquatic environment when they use large amounts of cooling water: 1. the intake of cooling water by a facility can cause the entrapment and impingement of fishes upon plants' intake structures; 2. entrainment can have a damaging effect upon smaller aquatic organisms such as plankton, fish eggs, fish larvae, and shellfish larvae; and 3. the discharge of heated cooling-waters into the aquatic environment can disrupt the function of complex and highly productive natural systems (Bugbee, 1977). The effect of entrainment on larval fish numbers is the focal point of this study.

Wickliff (1931) suggested and recent studies have supported (Heniken, 1977; Bartholomew, 1978; Cole, 1978a; and Waybrant and Schauer, 1979) that the nearshore zone of Lake Erie is a valuable fish spawning and nursery area. The movement of larval fishes is often controlled more by water movement than by swimming ability (Houde, 1969). Thus the high densities of larval fishes and buoyant fish eggs in nearshore areas are highly susceptible to the hazards posed by high volume cooling water intakes.

Congress approved and the President signed into law, on October 18, 1972, The Federal Water Pollution Control Amendments of 1972, (Public Law 92-500), the objectives being to restore and maintain the chemical, physical, and biological integrity of the nation's navigable waters. Sections 316 (A) and (B) of this act, respectively, deal with the effects of thermal discharges and cooling water intakes upon the biological system. These sections created a need for detailed knowledge of fish eggs and larvae, also known as ichthyoplankton (Boreman, 1976). Prior to the passage of this legislation, scientific investigations of the egg, embryonic, and larval stages of fish received cursory attention in comparison with many other aspects of freshwater fishery science. In reference to Lake Erie, very few studies exist and few have examined more than species composition of larval fishes.

Marie Poland Fish (1932), in her classic study, described the early developmental stages of 62 species of fish found in Lake Erie and its tributaries. This study produced an important atlas of developmental stages of these species but gave little insight into the abundance or distribution of these fishes. Discussing this project, Wickliff (1931) noted that greater species diversity and higher numbers of fish larvae were captured around the island region of the Western Basin and in the nearshore zone than offshore.

The Ohio Division of Wildlife sampled Sandusky Bay for young-of-the-year fishes with beach seines. Eighteen species were captured (Chapman, 1955). The Ohio Division of Wildlife also conducted a study attempting to locate major walleye spawning grounds in the Western Basin of Lake Erie. Walleye eggs and larvae were found to be most abundant in areas that have hard, rocky bottoms (Keller, et al., unpublished).

Most recent larval fish investigations in the United States have been conducted as required by Section 316(b) of Public Law 92-500. A number of such studies have been conducted in Lake Erie. Unfortunately, these studies tend to report efforts concentrated in limited areas and have a very limited circulation. Larval fish in the Locust Point area of the Western Basin have been studied by Reutter and Herdendorf, (1975) as part of the pre-operational, and post-operational study (Reutter 1978a; 1978b; 1979a; 1979b; 1980a; 1980b), for the Davis-Besse Nuclear Power Station (CLEAR Tech. Rept. No. 78a and 78b). Reutter (1979a and b) also reported on entrainment at Toledo Edison's Acme and Bayshore plants. Hartley and Herdendorf (1976) reported the work of Donald Davis on larval fishes found during a study of a proposed power plant site in the Sandusky Bay area. This report will summarize portions of a series of studies (Bartholomew, 1979; Heniken, 1977; Herdendorf, 1977; Herdendorf and Cooper, 1975 and 1976; Herdendorf, Cooper, Heniken and Snyder, 1976 and 1977; Reutter, Herdendorf and Sturm, 1978a and 1978b; and Snyder, 1978) conducted in Western Basin waters including the Maumee and Sandusky River estuaries between 1975 and 1977. The extent of fish production in these downstream or estuarine portions of the lake has received little attention until recent times. Studies of larval fishes in the Central Basin include one reported by the United States Nuclear Regulatory Commission (1974) at Berlin Heights and one conducted by Aquatic Ecology Associates (1978) for a proposed United States Steel plant in Conneaut, Ohio.

Without question, the most complete study of larval fishes in Lake Erie is the overall program, of which the present study is a part, designed to assess the impact to cooling water intakes in Michigan and Ohio. This study was funded and coordinated by the Large Lakes Research Station (Grosse Ile, Michigan) of the United States Environmental Protection Agency and included sampling in Ohio, Michigan, and Canadian waters of Lake Erie, along with other on-site studies (Nelson and Cole, 1975; Heniken, 1977; Snyder, 1977; Cole, 1978a and 1978b; Patterson, 1979; Waybrant and Shauver, 1979).

Environmental studies in the vicinity of Detroit Edison's Monroe, Michigan site began in 1970. Larval fish studies were initiated in 1973. A large multi-agency study of larval fish distribution was funded by the Large Lakes Laboratory, USEPA, in 1975. Data collected by personnel from The Ohio State University, Michigan Department of Natural Resources and Michigan State University allowed Dr. Richard Patterson of the University of Michigan to estimate losses of yellow perch due to entrainment in 1975 and 1976 at the 3200 MW generating facility at Monroe. Personnel from The Ohio State University collected samples in the nearshore zone of the Western Basin in 1977 to provide additional data for Dr. Patterson's model calculations. Collections were made in the nearshore zone of the Central Basin in 1978. This study makes independent entrainment estimates for selected power plants in the Western and Central Basins. In addition, the distribution and abundance of selected larval fish species are described for the study period extending from May, 1975 to August, 1978.

SECTION 2
CONCLUSIONS

1. Sampling procedures employed were selective for species inhabiting limnetic areas and may not adequately represent species which inhabit littoral regions.
2. Abundance estimates were made. The resultant standard deviations and standard errors of the mean calculated were large but were smaller, i.e., improved, when mean densities exceeded 100 fish/100 m³.
3. The capture of whitefish larvae on reefs and along the Michigan and Ohio shorelines indicated that a remnant spawning population of whitefish was inhabiting the Western Basin.
4. The capture of sculpin larvae on reefs in the island area indicated that a remnant spawning population of sculpins was inhabiting the Western Basin.
5. The Maumee River estuary contained higher densities and greater estimated numbers of larvae than the Sandusky River estuary. Production estimates of gizzard shad and freshwater drum in the two estuaries often approached or matched the production estimates of these species in the Western Basin study areas.
6. Both the Maumee and Sandusky River estuaries are important spawning and nursery sites for gizzard shad, white bass, walleye and freshwater drum.
7. Higher densities of gizzard shad, white bass and freshwater drum were captured in Maumee Bay and in Sandusky Bay than along either the Ohio or Michigan shorelines. This would indicate that these areas are valuable nursery areas for these species. The high densities of larvae in these areas may result from spawning in the bay as well as result from larvae carried into the bay areas by river currents.
8. Rainbow smelt and yellow perch larvae were almost entirely restricted to the lake proper.
9. In the Western Basin in 1975 and 1976, larval yellow perch were found predominantly in nearshore areas associated with sandy and/or gravel substrate. Perch larvae were concentrated near the bottom. Walleye larvae were collected in the same areas as perch larvae in the nearshore zone as well as offshore on the reefs.
10. Higher densities of rainbow smelt and emerald shiner were collected at stations in deeper open water station than at stations located adjacent to the shoreline.

11. In the Western Basin in 1977, larval yellow perch densities were highest in the area along the Michigan shoreline north of Woodtick Peninsula and south of the River Raisin. The larvae found here may have been carried into and retained in this area by the eddying effects of the Maumee and Detroit Rivers, as suggested by the fact that spawning habitat in the area is not ideal for yellow perch.
12. In the Western Basin, yellow perch and walleye larvae densities were generally highest along the Ohio shoreline, particularly in the Locust Point area. The sandy, gravel bottom and offshore islands and shoals provide the best spawning habitat for these species remaining in Lake Erie.
13. High densities of pro-larval smelt captured along Cedar Point in the Central Basin indicated that the area probably is being used as a spawning site for rainbow smelt. If so, this would be the first record of smelt spawning that far west along the United States shoreline.
14. The capture of larval freshwater drum was limited to the western half of the Central Basin study area. Freshwater drum prefer water less than 12 meters deep. East of Cleveland, water less than 12 meters deep is limited to a very narrow band along the shoreline, limiting spawning habitat.
15. In 1978, highest densities of larval yellow perch sampled were found in the eastern third of the Central Basin study area. Perch in the area are believed to be using the harbor breakwalls and sands collected in the quiet areas of these structures as spawning habitat.
16. Because fish densities were highest in the Maumee estuary and Bay, and since Toledo Edison's Bayshore Plant is located at the mouth of the Maumee River, entrainment is likely to be higher at the Bayshore plant than at any other power plant studied.
17. Significant differences were found between entrainment estimates derived from field collections and in-plant collections at Central Basin power plants.
18. In-plant estimates of entrainment, when samples are collected with submersible pumps, are believed to give a better estimate of entrainment than field collections made with metered nets. Avoidance of the sampling gear is not as much a problem for pump samplers as it is for nets.
19. Using in-plant collections entrainment estimates were highest at the Avon Lake power station. A total of 231,543,500 larvae or 60.1% of total entrainment in the study area of the Central Basin occurred here. Cyprinids accounted for 53% of the Avon Lake entrainment total.

20. Yellow perch entrainment was calculated to be highest at the Avon Lake and Ashtabula A and B plants. An estimated 1,340,500 yellow perch larvae were estimated to have been entrained at Avon Lake and 1,315,417 at the Ashtabula A and B Plant.
21. Estimates of entrainment at the Ashtabula A and B Plant and the Ashtabula C Plant represent a comparison of entrainment losses due to inshore and offshore intakes. The Ashtabula C Plant, where the water intake is located 1200 meters offshore, has 78% of the water requirement of the Ashtabula A and B Plant with an intake located 425 meters offshore. Estimates of entrainment were found to be much lower for the C Plant in all cases except rainbow smelt, which was 10 times higher. Yellow perch entrainment at the C Plant was found to be 20% of that at the A and B Plant.
22. Central Basin entrainment estimates generally represented between 2 and 4% of total estimated nearshore production. Yellow perch entrainment represented 3% of total yellow perch production. The highest percentage of any species entrained was carp, as 36% of the total nearshore carp production was entrained.

SECTION 3

SITE DESCRIPTION

The southern border of the Great Lakes Basin from Green Bay, Wisconsin to Rochester, New York has been characterized as the "industrial crescent", the premier heavy manufacturing region in the United States. Its people produce 70% of the nation's steel, 66% of the nation's autos, and almost 50% of its metals and machinery (Great Lakes Communicator 1980. Large industrial centers such as Buffalo, New York; Cleveland and Toledo, Ohio; and Detroit, Michigan make Lake Erie the center of Great Lakes manufacturing, therefore this region has a massive requirement for electrical power. Lake Erie serves as the major source of cooling water for these facilities.

Lake Erie is unique among the Great Lakes by reason of several of its natural characteristics. It is the shallowest, having a mean depth of 18.5 meters and a maximum depth of 64.0 meters. It is the southern-most and warmest, with midlake surface water temperatures reaching an average maximum of about 24°C. Lake Erie has the shortest flow-through time, approximately 2½ years. It is the most biologically productive of the Great Lakes and is the only one with its long axis parallel to the prevailing winds (Browne, 1975).

Of considerable ecological importance is the natural morphological division of Lake Erie into three basins: Western, Central, and Eastern (Hartman, 1972). Of concern to this study is the immediate nearshore zone of the Western and Central Basins. Due to the dependence of successful fish reproduction on physical characteristics of the spawning area, an understanding of the Western and Central Basins is useful. The major features of these basins are discussed below.

WESTERN BASIN

The Western Basin is the focal point of many competing interests. Manufacturing industries in Detroit and Toledo use the lake and its tributaries for industrial source water. Great Lakes shipping industries especially utilize the Western Basin in the ports of Toledo and Detroit. These interests compete directly with an extensive recreation industry centered on sport fishing and boating. A resilient commercial fishing industry persists in the face of bans and prohibitions; and a vocal charter fishing industry is growing here in the wake of increasing fish stocks.

The Western Basin lies west of an island chain extending from Point Pelee, Ontario to Marblehead, Ohio (Figure 1) (Upchurch, 1976). The basin bottom is essentially a flat mud plane with sharply rising rock islands and shoals along the southern and central portions of the basin. The Western Basin reaches a maximum depth of 20.4 meters with an average depth of 7.4 meters, making it the shallowest of the three basins. The Western Basin is also the smallest basin, having a surface of 3276 km² (13% of the total lake surface area) and a volume of 24.2 km³ (5.1% of the total lake volume) (Hartman, 1972).

Several environmental conditions in the Western Basin are unique in Lake Erie. Primary productivity and turbidity are higher here than in the other basins of the lake (Fay, 1976; Hartley, *et al.*, 1966). Winds effectively mix the water column, allowing isothermal conditions to exist most of the time (Hartley, *et al.*, 1966 Patuzkey, 1966). Temporarily stratified conditions do occur, but only after extended periods of hot calm weather (Patuzkey, 1966). Winds also subject this basin to extreme short-term lake water level fluctuations, especially during storm periods (Hartley, *et al.*, 1966). And the overall shallow nature of the basin with its rock islands and shoals make it the most important spawning and nursery grounds in the lake (Hartman, 1972).

Two major rivers, the Detroit and Maumee Rivers, and several smaller streams empty into the Western Basin. The Detroit and Maumee Rivers together provide over 93% of the total water flow into Lake Erie. The Detroit River accounts for over 90% of the total having an average discharge of 4,988 m³/sec, while the Maumee River at 187 m³/sec and accounting for only 3.4% of the flow into the lake, contributes 34% of the total sediment loading (Lewis and Herdendorf, 1976). Table 1 lists the streams in the study area, their flow rates and sediment loadings. Streams entering the study area have downstream portions influenced by lake conditions and may properly be described as freshwater estuaries (Brant and Herdendorf, 1972).

Although surface flow in the Western Basin is often changed by changes in wind direction and intensity, currents in the Western Basin are dominated by the Detroit River inflow. Figure shows the inflow pattern of Detroit River water and dominant summer surface currents. This shows a definite southern movement of midchannel Detroit River water with eddy effects along the sides of the midchannel flow. These eddies lead to sluggish movement of surface water between Stony Point, Michigan and Toledo, Ohio. Bottom currents, as shown in Figure , are very similar to surface currents being dominated by the Detroit River inflow. An eddy effect along the western side of the Detroit River inflow between Stony Point, Michigan and the mouth of Maumee Bay tends to partially retain input materials leading to higher concentrations of water-quality related constituents in this area (U. S. Department of the Interior, 1968).

For purposes of comparison and discussion, the Western Basin is divided into three physiographic regions: the Michigan shoreline, Maumee Bay, and the Ohio shoreline. A closer look at the characteristics, particularly geologic, of each area follows.

Michigan Shoreline

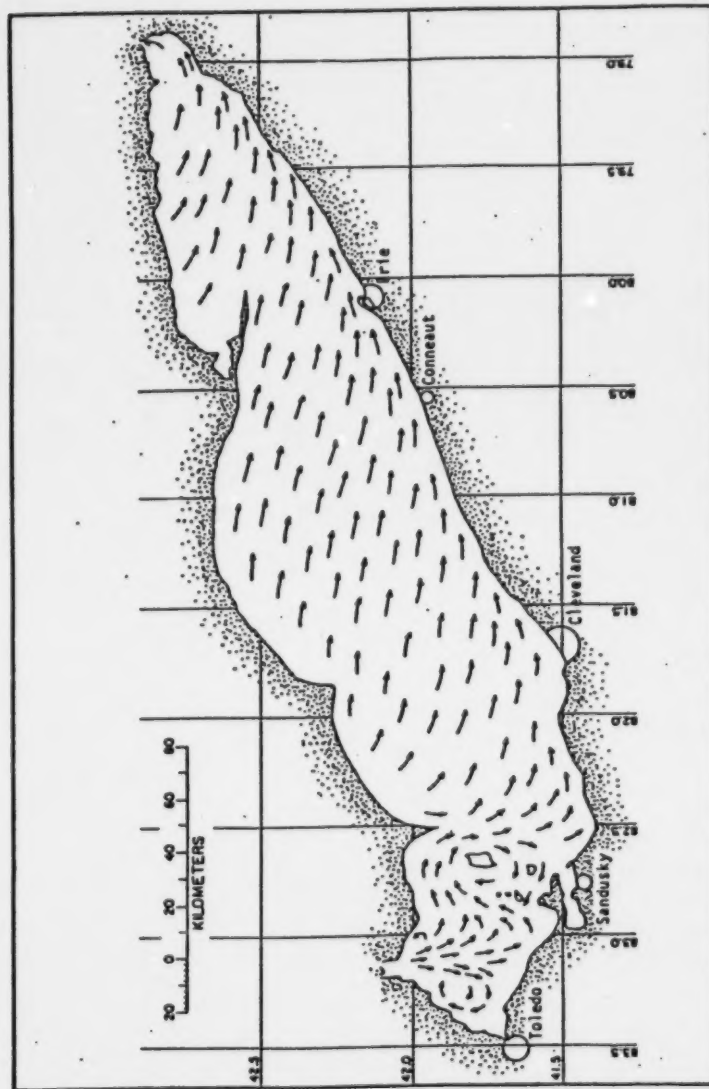
Along the 30-mile stretch of shoreline between the Detroit River and Maumee Bay the dominant littoral drift is southwest. The shoreline is low, marshy and composed of unconsolidated till and lake deposits, except for an outcrop of Silurian dolomite at Stony Point seven miles north of Monroe. A sandy spit, Woodtick Peninsula and North Cape has formed a bay-mouth bar at the northern margin of Maumee Bay from material eroded from the low bluffs along the Michigan shoreline (Herdendorf, 1973). Marshy areas and the area around Woodtick Peninsula and North Cape are excellent spawning habitat for many lake fish species.

TABLE 1. STREAMS IN THE STUDY AREA

STREAM	AVERAGE DISCHARGE (m ³ /sec)	% OF LAKE ERIE TOTAL	SUSPENDED SOLIDS (mtons/year)	% OF LAKE TOTAL
<u>WESTERN BASIN</u>				
Michigan				
Detroit	4988	90.0	1.42×10^6	25.7
Huron	16	0.3	1.63×10^3	0.1
Raisin	19	0.3	4.26×10^3	0.1
Others	20	0.4	3.69×10^3	0.1
Ohio				
Ottawa	3	0.1	9.07×10^2	0.1
Maumee	187	3.4	1.06×10^6	37.1
Toussaint	3	0.1	6.35×10^2	0.1
Portage	17	0.3	1.09×10^5	2.0
Sandusky River	8.6	0.2		0.1
<u>CENTRAL BASIN</u>				
Huron	11	0.2	1.09×10^4	0.2
Vermilion	9	0.2	8.16×10^3	0.1
Black	14	0.2	1.39×10^4	0.3
Rocky	9	0.2	2.68×10^4	0.5
Cuyahoga	23	0.4	2.36×10^5	4.3
Chagrin	9	0.2	3.18×10^4	0.6
Grand			1.92×10^5	3.5
Ashtabula	3	0.1	4.99×10^3	0.1
Conneaute	6	0.1	3.63×10^3	0.1
Others	31	0.6	1.81×10^5	3.3

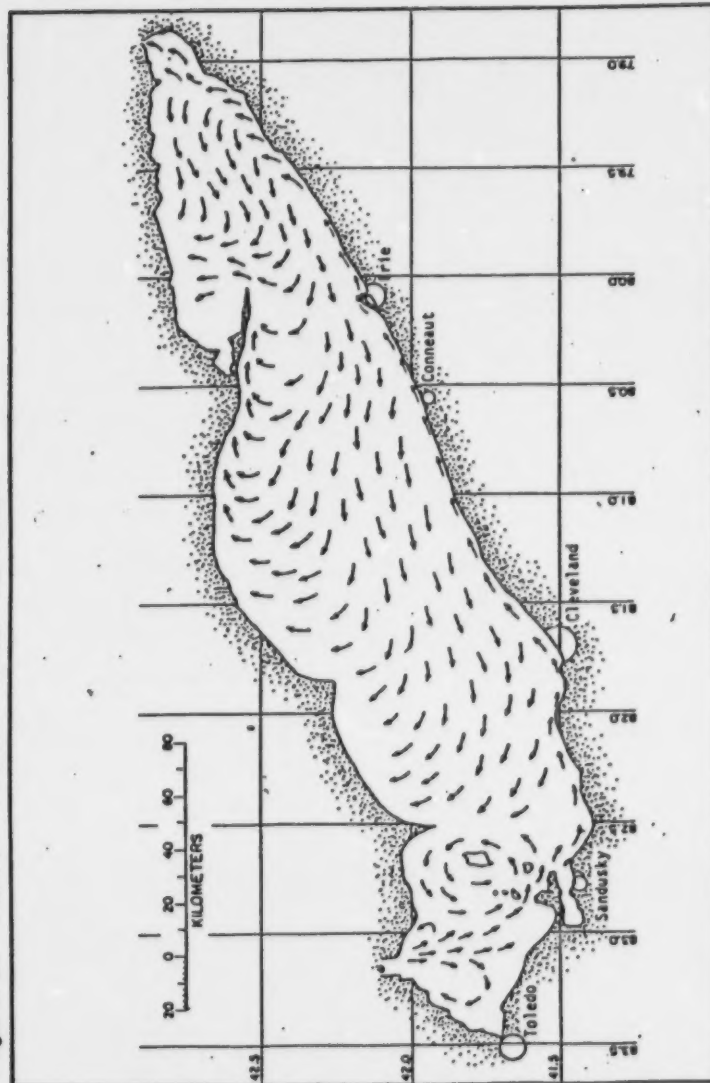
Source: Lewis and Herdendorf (1976)

Figure 1. Dominant Summer Surface Currents.



Source: U.S. Dept. of Interior, 1967.

Figure 2. Dominant Summer Bottom Currents.



Source: U.S. Dept. of Interior, 1967.

The bottom here slopes gently from the shore out to an 8-meter depth, 5-10 miles offshore (U. S. Department of the Interior, 1968). A thin band of sand and gravel lines the shoreline with the bottom offshore made up of a mud sand mixture (Thomas *et al.*, 1976). Several small streams of little more than local importance enter the Western Basin here (Table 1). The largest of these, the River Raisin, is used extensively as a water source for industrial purposes and electrical generation.

Maumee Bay

Maumee Bay lies at the western-most end of Lake Erie between 41°41'N and 41°45'N latitude and 83°20'W and 83°29'W longitude. It is separated from Lake Erie by two spits (Figure 1): (1) Woodtick Peninsula, with North Cape at its southern tip, extends southerly from the Michigan shoreline; and (2) Little Cedar Point projecting northwesterly from the Ohio shore (Herdendorf *et al.*, 1978). At the mouth of the Maumee River, Maumee Bay is very important as a nursery area for different species and many fish reside there throughout their first summer before moving out into the lake (Herdendorf and Cooper, 1975; Fraleigh *et al.*, 1974).

Bathymetrically, Maumee Bay is a broad shallow shelf sloping gently downward toward the northeast. The maximum depth is 3 meters below low water atum and mean depth is 1.5 meters. Bisecting Maumee Bay in a northest-southwest direction is a navigation channel maintained annually to a depth of 10 meters. Adjacent to the channel, about 2000 feet from either side, is a series of linearly arranged dredge spoil islands and shoals, composed of sandy material, creating possible spawning sites for walleye, yellow perch and white bass.

The shoreline of Maumee Bay is characterized by low clay bluffs, is highly developed as a residential/industrial area to the west and grading through a less intense development on the south to marsh on the northeast. Bottom material is lacustrine clay with a thin overburden of recently deposited silt, except near Little Cedar Point where a relatively thick overburden of sand exists (Herdendorf, 1975).

Ohio Shoreline

The 21-mile shoreline between Little Cedar Point and Port Clinton, Ohio is characterized by a northwest drift. Elongated, dominately sandy bodies of low relief, their long axes lying essentially parallel to the trend of lake bottom contours, dominate much of the area east of Little Cedar Point. These features lie lakeward of extensive marshy areas and lowlands, most of which have been diked. The sandy bodies are composed mostly of fine, well-sorted sand. Coarser sand and fine gravel are dominant fractions in surf zone.

The nearshore bottom slopes very gently lakeward. As distance is increased offshore the sand particles gradually become smaller in size. A short distance offshore a band of fine lacustrine clay lies parallel to the shoreline. Northeast of this band of clay, between Wards Canal and Marblehead Peninsula lie extensive areas of sand, gravel and rocky shoals (Pincus, 1960). These areas provide perhaps the best spawning habitat in the study area.

CENTRAL BASIN

Along the Ohio reach of the Central Basin the predominate feature is a complex of residential, commercial and industrial development extending almost continuously from the low lake planes near Sandusky to the high bluffs at Painesville, Ashtabula, and Conneaut. Few if any natural areas remain. Overall the impression is a relative homogenous environment characterized by extensive development. Water use in the Central Basin is largely limited to shipping and heavy industry; recreational uses are confined to tributaries and the immediate nearshore zone. Recreational fishing is largely limited to the tributaries, piers, and breakwalls. Commercial fishermen, however, catch more yellow perch annually in the Central Basin than in the Western Basin (Davies et al., 1979).

The Central Basin is separated from the Western Basin by the rock escarpment previously described and from the Eastern Basin by a relatively shallow sand and gravel bar of glacial moraine origin extending between Erie, Pennsylvania and Long Point, Ontario (Figure 1) (Upchurch, 1976). With a surface area of 16,177 km² and a volume of 299.2 km³ the Central Basin is the largest of the lake's three basins (63% of both surface area and volume of the entire lake). The Central Basin has a maximum depth of 25.6 meters and a mean depth of 18.5 meters (Hartman, 1972).

Several environmental conditions are radically different here than in the Western Basin. Because of the larger size and the fact that streams entering the Central Basin do not carry silt loads comparable to those of the Detroit and Maumee Rivers, turbidity is generally much lower here than in the Western Basin. By June most of the waters in the Basin are thermally stratified, with percent oxygen saturation in much of the hypolimnion approaching zero by August (Burno, 1976). Perhaps of most interest for commercial and sport fish is the fact that the bottom slopes away from the shoreline at a much greater rate here than in the Western Basin, limiting potential spawning areas to a narrow band along the shoreline.

Rivers flowing into the Central Basin are small when compared to the Detroit and Maumee Rivers (Table 1). Industrial development here is extensive and most of the rivers are utilized for industrial source water. All of these rivers except for the Vermilion, Rocky and Chagrin Rivers, have extensively dredged bottoms and are used as lake front ports.

The effect of wind dominant currents in the Central Basin. With its long axis essentially parallel to the prevailing southwesterly wind, this effect is especially important (United States Department of the Interior, 1968). However the dominant summer surface flow as depicted in Figure 1 shows a definite flow of Western Basin water through Pelee Passage and subsequently southward to move parallel along the southern shore of the lake. Bottom currents, (Figure 2) on the Central Basin are not similar to surface flow. Because surface currents are generally moving water in much greater quantities than can be removed from the Basin, the balancing movement must be subsurface and essentially a return flow over most of the basin (U. S. Department of Interior, 1968), in opposition to the surface flow.

Mud covers more than two-thirds of the bottom of the Central Basin. A very narrow strip of sand and gravel can be found along most of the Ohio shoreline. This strip reaches its greatest width of 5 miles or more between Cleveland and Fairport, Ohio (U. S. Department of Interior, 1968). Sand deposits can also be found on the bottom of the eastern sides of breakwalls at the Huron, Vermilion, Grand, and Ashtabula Rivers, and Beaver and Conneaut Creeks (Herdendorf, 1963). For many species of fish, spawning habitat in the Central Basin is limited to man-made structures and estuarine environments of streams entering the area.

SECTION 4

METHODS

SAMPLING

The open lake portion of the study area in 1975 and 1976 encompassed approximately 1740 sq. km of Ohio and Ontario waters of the Western Basin of Lake Erie (Figure 3). This portion of the lake was subdivided for study purposes into six depth zones, referenced to National Oceanic and Atmospheric Administration, U.S. Department of Commerce, navigation chart 39 of Lake Erie. A two-meter contour interval was used to delineate each depth zone, each zone consisting of a vertical column of water bounded by two depth contours.

Sampling stations were established in a stratified random pattern. A total of 56 stations were sampled during 1975 and 60 stations were sampled during 1976. A total of nine cruises were made between May 12 and September 3 during 1975 and fourteen cruises between April 12 and September 3 during 1976.

Collections in the open lake were made during the daylight hours with conventional plankton nets (0.75 m diameter, 0.760 mm mesh, conical design). Flow rates through the nets were measured with calibrated General Oceanic flowmeters located slightly off-center in the nets. The meters were calibrated by multiple tows of the meter suspended in a bridle over a known distance. During the sampling period, the nets were towed in a circular pattern to avoid propwash. Tows were conducted at speeds of 2-5 knots from a 21-foot Boston Whaler. A single surface and bottom tow was made at each station. A single tow was made at stations where water was less than one meter deep. Stations were located with the aid of landmarks and a variety of stationary navigational aids.

The Maumee River portion of the study area encompassed a 14 sq km zone extending from the river mouth to the riffles above the head of the estuary at Perrysburg, Ohio, a distance of 28.2 km (Figure 3). Sampling stations were located at the river mouth and at points in the lower estuary at 8.4 km upstream, approximately mid-estuary at a distance 14.8 km upstream and at the head of the estuary 25.4 km upstream. Stations at the lower three locations were sampled in 1975 and 1977. In 1976, a station at the head of the estuary as well as one in the riffle above the estuary was sampled. Stations were sampled bimonthly between May 15 and October 3 in 1975, twice weekly between April 7 and June 8 in 1976, and weekly or twice weekly between March 16 and September 1 in 1977.

The Sandusky River portion of the study area encompassed a 2 sq km zone extending from the river mouth at the head of Sandusky Bay to the upper limit of the estuary at the Fremont, Ohio riffle, a distance of 24.9 km (Figure 3). Four stations, including one within the riffle, were sampled twice weekly between April 12 and June 7, 1976. Sampling stations were located at the river mouth and at points 8.9 km, 15.1 km and 24.9 km upstream.

Collections in the estuaries were made during the daylight hours with conventional plankton nets (0.75 m diameter, 0.760 mm mesh, conical design). A limited number of samples were collected during the night-time hours in 1976. Plankton nets with 0.571 mm mesh netting were used in 1977. Flow rates through the nets were measured with calibrated General Oceanic flowmeters located slightly off-center in the nets. The meters were calibrated by multiple tows of the meter suspended in a bridle over a known distance. During the sampling periods, the nets were towed in a circular pattern from an outboard motor powered boat. Samples in the riffles were taken by walking a hand-held net over a known distance. A single surface and bottom sample was collected at each station in 1975 and 1976. Triplicate surface and bottom samples were collected at stations in the lower portion of the estuary in 1977.

A total of ten transects in the nearshore portion of the Western Basin (five located along the Michigan shore, two within Maumee Bay and three along the Ohio shore) were sampled during eight cruises between April 13 and July 8, 1977 (Figure 4). Five replicate samples were collected at each of three stations composing each transect. The mean density of the five replicates was calculated and standardized to the number of larvae per 100 cubic meters based upon the volume filtered. Along the Ohio and Michigan shores, stations were located immediately nearshore at the 1 to 1.5 meter depth contour and further offshore at the 3 and 5 meter depth contours. Transects ran perpendicular to the shoreline. Within Maumee Bay, the two transects were located east and west of the navigation channel and ran parallel to the channel. Maumee Bay stations were located in water two to three meters deep. All stations were located with the aid of lighted landmarks, a variety of lighted aids to navigation and a lead line. Oblique full stratum tows were made during the night with conventional plankton nets (0.75 m diameter, 0.571 mm mesh, conical design). Tows were conducted at speeds of 2-5 knots from a 21-foot Boston Whaler.

A total of ten transects in the nearshore zone of the Central Basin portion of Lake Erie were sampled during eight cruise periods between May 2 and August 9, 1978 (Table 5). In addition, three river mouth locations (Grand River, Black River, and Huron River) were sampled during the eight intervals. Four replicate samples were collected at three stations composing each transect. The mean density of each species of fish was calculated and standardized to report the number of larvae per 100 cubic meters of water. Stations were located immediately nearshore at the one to two meter depth contour (this contour depth was absent and samples were not collected at this station for a transect in the vicinity of Cleveland) and offshore at the five and ten meter depth contours. Transects ran perpendicular to the shoreline. All stations were located with the aid of lighted landmarks and depth meters or lead lines. Oblique full stratum tows were made during the night with conventional plankton nets (0.75 m, 0.571 mm mesh, conical design).

Field collections were preserved in buffered 5 percent formaldehyde solution. Larvae from each sample were identified to the lowest taxon possible, counted, measured for total length and transferred to a 70 percent ethanol solution. Several species, which are morphologically similar during their early developmental stages, could not be efficiently

FIGURE 3. STATION LOCATION AND DELINEATION OF STUDY AREA DURING 1975-1976 STUDY PERIOD

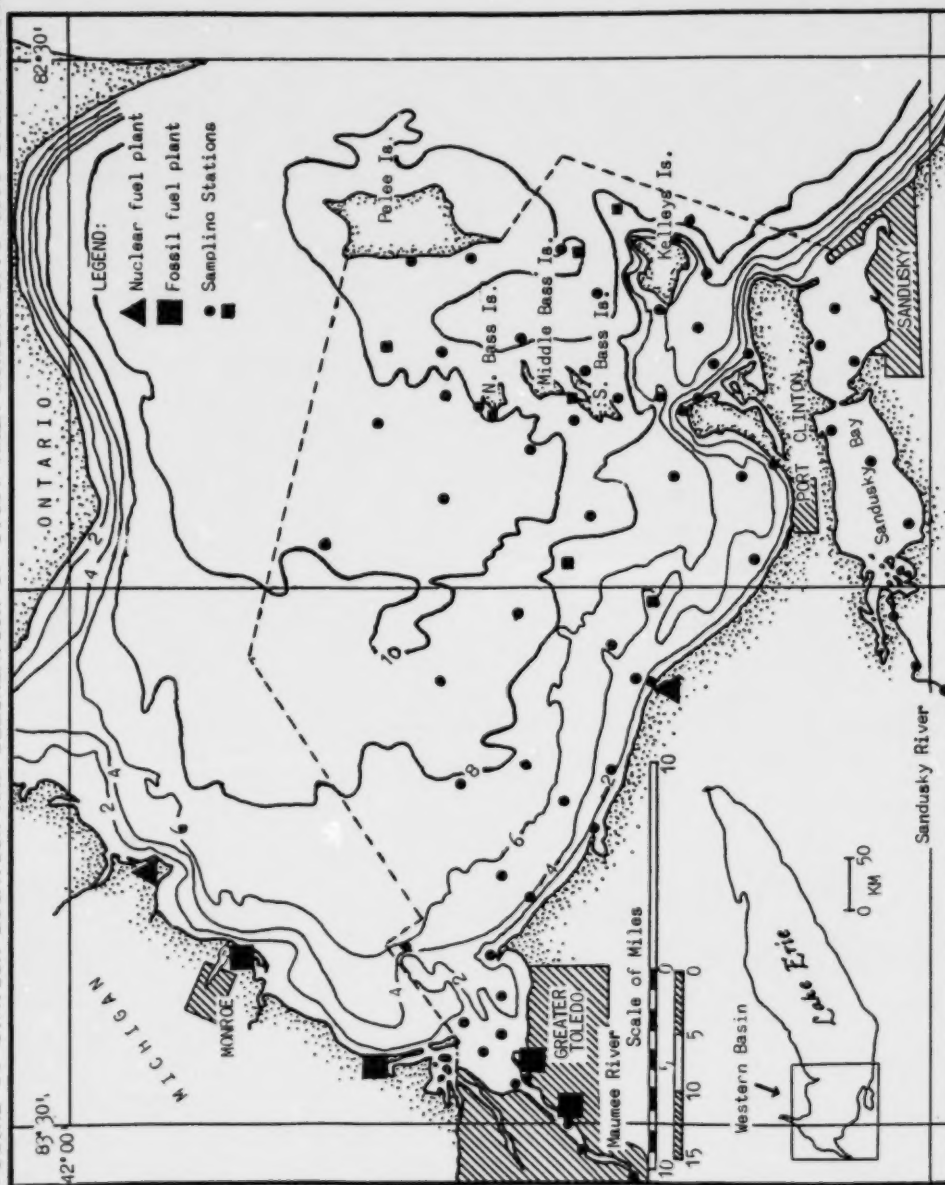


Figure 4. LOCATION OF THE SAMPLING STATIONS IN THE WESTERN BASIN OF LAKE ERIE - 1977.

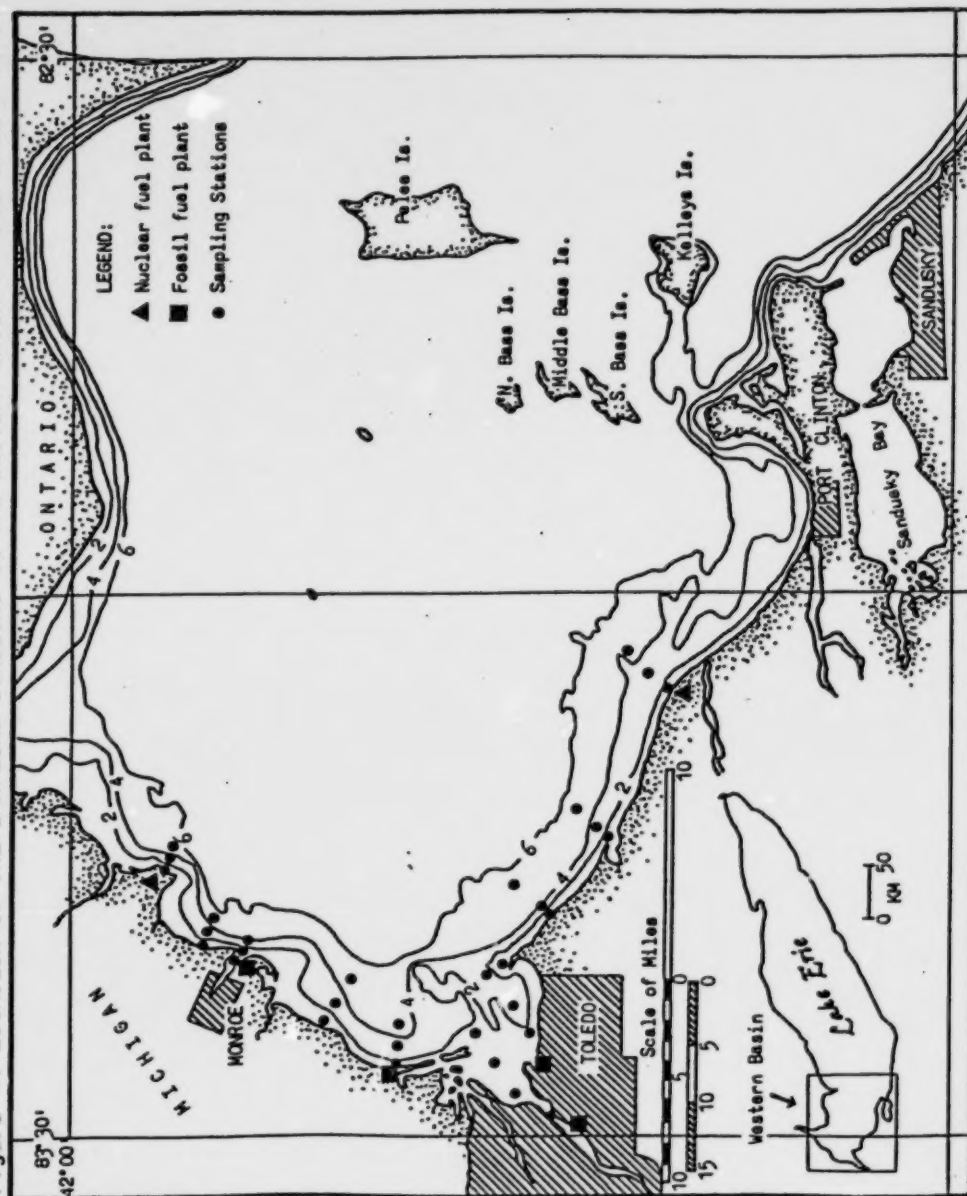
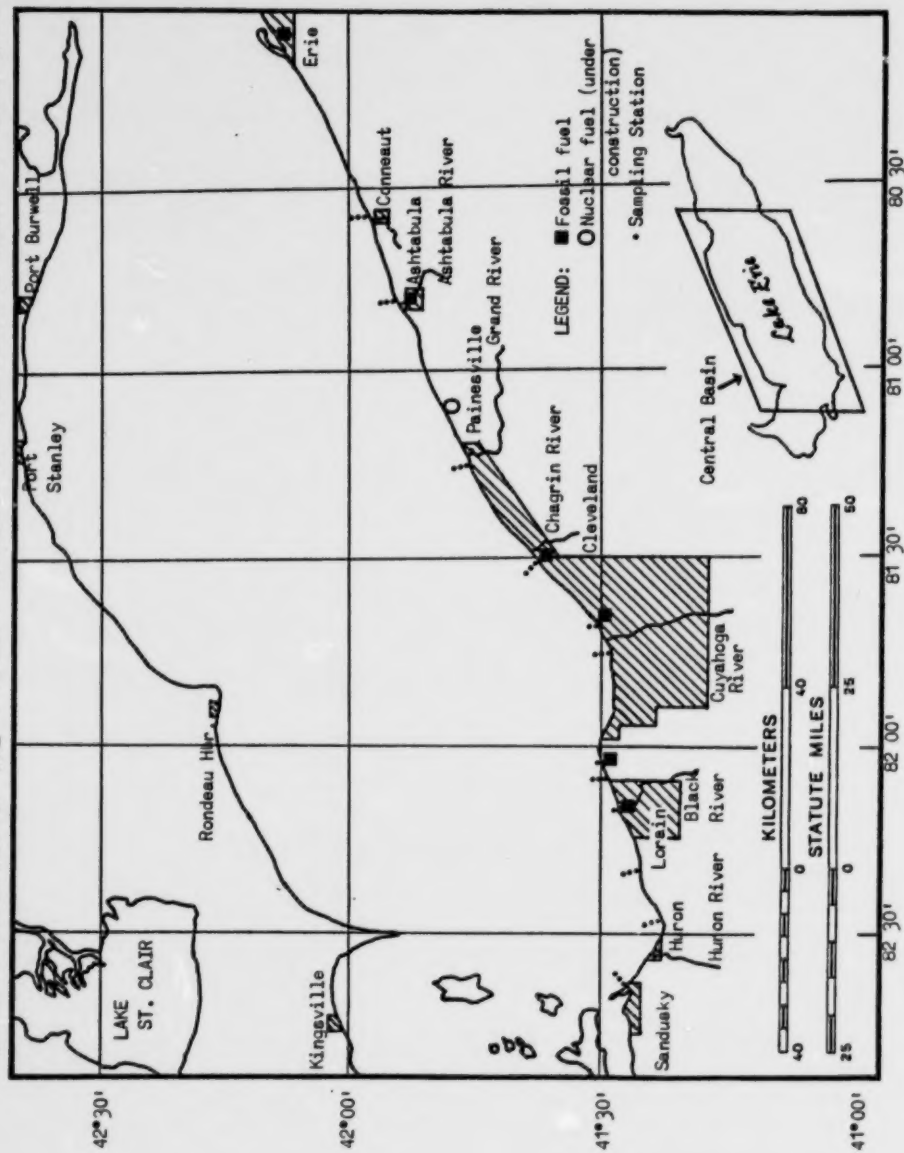


Figure 5. LOCATION OF THE SAMPLING STATIONS IN THE CENTRAL BASIN OF LAKE ERIE - 1978.



separated in large samples. Gizzard shad and alewife were grouped and reported as gizzard shad/alewife. Carp and goldfish larvae and their hybrids were similarly grouped and are reported by carp/goldfish. White bass and white perch larvae were grouped and reported as white bass/white perch. Black crappie and white crappie are reported as crappie. All sunfish specimens are reported as sunfish. This study included both prolarval and postlarval developmental stages which were determined according to the definitions of Hubs (1943). Developmental stages of selected species were also determined according to the definitions of Snyder and Snyder (1978). Common and scientific names used in the text are listed in Table 2. The data was punched onto computer cards and all calculations and statistical procedures were performed using either an IBM 360 or an Amdahl 470 computer housed at the Instructional and Research Computer Center of The Ohio State University (Barr, 1976; Hollander and Wolf, 1973).

For purposes of analyzing onshore-offshore distribution along near-shore transects sampled during 1977 and 1978 the study area was divided into three depth zones: depth zone 1 contained all water 0-1 meter deep; depth zone 2 contained all water 1-3 meters deep in the Western Basin and 1-5 meters deep in the Central Basin, and depth zone 3 contained water 3-5 meters deep in the Western Basin and 5-10 meters deep in the Central Basin.

Volume weighted estimates of the total number of larvae in each of these depth zones were calculated. To do this it was necessary to make two assumptions: (1) concentrations of larvae changed linearly from one station to another; and (2) the catch at each station was representative of larvae concentrations of a volume of water extending to a point mid-way between stations along the transect.

Characteristics of power plants located along the Western Basin are summarized in Table 3 and the characteristics of power plants located along the Central Basin are summarized in Table 4. Open lake samples were used to estimate the number of larvae entrained at each power plant along the shoreline of our study site. These were calculated by multiplying the density of larvae at our station closest to the power plant water intake by the average flow rate for that power plant per day. No stations were sampled in close proximity to the intakes of the Toledo Edison Bayshore plant as a part of this study or Consumers Power's Whiting plant. For these power plants average larvae concentrations in Maumee Bay were used. It was assumed that concentrations of larvae change linearly with time, and cooling water flow rates remained constant through the study period.

Finally, at six power plants along the shoreline of the Central Basin: Edgewater, (Lorain), Avon Lake, Eastlake, Ashtabula A, B and C, in-plant ichthyoplankton samples were collected weekly with the cooperation of the respective utility companies. These samples were taken to provide an estimate of the impact of power generation on fish populations in the lake. Samples for the Edgewater Plant were collected and identified by Geo-Marine, Inc. Collections at the other five plants were collected and identified by Applied Biology, Inc. Necessary information regarding collection techniques is presented in Table 5.

TABLE 2. COMMON AND SCIENTIFIC NAMES OF FISH SPECIES
MENTIONED IN THE TEXT

COMMON NAME	SCIENTIFIC NAME
Lake Sturgeon	<u>Acipenser fulvescens</u>
Alewife	<u>Alosa pseudoharengus</u>
Gizzard Shad	<u>Dorosoma cepedianum</u>
Lake Trout	<u>Salvelinus namaycush</u>
Lake Herring or Cisco	<u>Coregonus artedii</u>
Whitefish	<u>Coregonus clupeaformis</u>
Rainbow Smelt	<u>Osmerus mordax</u>
Quillback Carpsucker	<u>Caprodes cyprinus</u>
White Sucker	<u>Catostomus commersoni</u>
Carp	<u>Cyprinus carpio</u>
Goldfish	<u>Carassius auratus</u>
Cyprinids	<u>Cyprinidae</u>
Golden Shiner	<u>Notemigonus crysoleucas</u>
Striped Shiner	<u>Notropis cornutus</u>
Emerald Shiner	<u>Notropis atherinoides</u>
Spottail Shiner	<u>Notropis hudsonius</u>
Bluntnose Minnow	<u>Pimephales notatus</u>
Channel Catfish	<u>Ictalurus punctatus</u>
Burbot	<u>Lota lota</u>
Trout Perch	<u>Percopsis omiscomaycus</u>
White Bass	<u>Morone chrysops</u>
White Perch	<u>Morone americana</u>
Rock Bass	<u>Ambloplites rupestris</u>
White Crappie	<u>Pomoxis annularis</u>
Black Crappie	<u>Pomoxis nigromaculatus</u>
Smallmouth Bass	<u>Micropterus dolomieu</u>
Sauger	<u>Stizostedion canadense</u>
Walleye	<u>Stizostedion vitreum vitreum</u>
Blue Pike	<u>Stizostedion vitreum glaucum</u>
Yellow Perch	<u>Perca flavescens</u>
Log Perch	<u>Percina caprodes</u>
Johnny Darter	<u>Etheostoma nigrum</u>
Greenside Darter	<u>Etheostoma blennoides</u>
Freshwater Drum	<u>Aplodinotus grunniens</u>
Mottled Sculpin	<u>Cottus bairdi</u>

TABLE 3. CHARACTERISTICS OF WESTERN BASIN POWER PLANTS.

Characteristic	Monroe	Whitting	Bay Shore	Davis-Besse
Location	Western Shore Lake Erie, Monroe, Michigan	Western Shore Lake Erie	Southwest Corner of Maumee Bay, Toledo, Ohio	South Shore Western Basin, Locust Point
Maximum Generating Capacity	3,150 Megawatts	345 Megawatts	623 Megawatts	906 Megawatts
Average Flow	$7.3 \times 10^6 \text{ m}^3/\text{day}$	$1.17 \times 10^6 \text{ m}^3/\text{day}$	$2.83 \times 10^6 \text{ m}^3/\text{day}$	$8.18 \times 10^4 \text{ m}^3/\text{day}$
Intake Location	Raisin River Mile 0.1	North Maumee Bay	Maumee River Mile 0.1	914 meters offshore, Water Depth 4 meters
Special Features	Draws water from the Raisin River Estuary	Draws water from Maumee River Estuary	Intake Channel 914 m drawing water from Maumee River Estuary	Only operational power plant in study area with cooling tower.

TABLE 4. CHARACTERISTICS OF CENTRAL BASIN POWER PLANTS

CHARACTERISTIC	Avon Point	Edgewater	Lake Shore	PLANT NAME Eastlake	Ashtabula A & B	Ashtabula C
Location	Avon, Ohio Avon Point	Southwest Corner of Lorain Harbor at mouth of Black River	Cleveland	Immediately West of the Mouth of Chagrin River	Immediately East of the Ashtabula River	Immediately East of the Ashtabula River
No. Electric Units	9 units	3 units	5 units	5 units	5 units	4 units
Gross Generating Capacity	1344 MW	175 MW	554 MW	1372 MW	499 MW	200 MW
Average Flow	832 Million gal/day m	146,000 gal/ day; 3.1 mil m	406 million gal/day; 1.5 million m	754 million gal/day 2.8 million m	286 million gal/day 1.1 million m	223 million gal/day 0.8 million m
Distance Offshore	375 m	350 m	375 m	40 m	425 m	1200 m
Depth of Intake	5 m	5 m	5 m	4.6 m	4.6 m	9 m

TABLE 5. IN-PLANT COLLECTION METHODS

CHARACTERISTIC	PLANT NAME				
	Avon Point	Edgewater	Lake Shore	Eastlake	Ashtabula A & B
Data Collected	Applied Biology Inc. 6-hour pump at surface, midchannel and bottom of intake channel behind traveling screens. Day and night samples	Geo-Marine Inc. Samples were obtained by tapping a line off one of two of Unit #3 circulating water lines Water filtered through 505- micron mesh plankton net	Applied Biology Inc. 6-hour pump at surface, midchannel and bottom of intake channel behind traveling screens. Day and night samples	Applied Biology Inc. 6-hour pump at surface, midchannel and bottom of intake channel behind traveling screens. Day and night samples	Applied Biology Inc. 6-hour pump at surface, midchannel channel behind traveling screens. Day and night samples.
Special Features	Intake curved NE to reduce effects of storms-drive debris into intake canal	Intake pro- tected by breakwalls	Intake curved NE to reduce effects of storms-drive debris into canal	Intake curved to W to mini- mize inflow of debris and warm water from Chagrin	Subsurface intake well offshore

SECTION 5

RESULTS

OVERVIEW

In 1975 and 1976, the study area encompassed the U.S. waters of the Western Basin, a limited portion of adjacent Ontario waters and the water of the Maumee River estuary and Sandusky River estuary. Personnel from The Ohio State University collected samples in Ohio and Ontario waters while personnel from Michigan State University and the Michigan Department of Natural Resources collected samples in Michigan and Ontario waters. The overall purpose of the effort was to gain a first-order approximation of the distribution and abundance of larval fish species in the U.S. and adjacent Ontario waters of the Western Basin. The study focused, in particular, on yellow perch larvae and the impact of entrainment of yellow perch larvae at the Monroe, Michigan electrical generating plant operated by Detroit Edison Company. An analysis of the impact of entrainment at this facility during the 1975 and 1976 period was reported by Patterson (1979). This study reports analyses of samples collected by Ohio State University personnel.

Subsequently, an intensive sampling effort was conducted in a portion of the nearshore zone of the Western Basin and the Maumee estuary in 1977 and in the nearshore zone of the south shore of the Central Basin in 1978. Independent analyses of the impact of entrainment at selected power plants were performed for selected species during each year of the study, 1975-1978.

SOURCES OF ERROR AND VARIABILITY IN SAMPLING

Inherent to all ichthyoplankton sampling programs are multiple sources of sample variability. This variability limits the reliability of the data, applicable statistical treatments and discussion of observed results. Therefore sample variability must be an important consideration when discussing ichthyoplankton investigations.

Several methods for collection of ichthyoplankton are available, each having special applications and each contributing to variability in a different way. Three different collection techniques were used in this study. Metered nets were used in the open lake survey and either submersible pumps or plant line taps were used to collect in-plant samples. When comparing results obtained using a variety of sampling gear, the limitations of each sampling method must be an integral part of the analysis.

Sources of sample variability have been identified as arising from three sources: (1) non-random spatial distributions of larvae; (2) mechanical problems inherent to the particular sampling gear used and (3) active avoidance of the sampling device (Weibe and Hollander, 1968). A brief discussion of these sources of variability, how they influence results of this particular study, and our efforts to control each follows.

The non-random distribution of larval fishes can affect the validity of assumptions upon which statistical treatments are based and limit the confidence that can be placed on data interpretation. Thus variation in the distribution (patchiness) are of primary concern and efforts must be made to keep variability to a minimum. The effects of patchy distributions can be minimized by collecting replicate samples and filtering large volumes of water during each sample collection (Weibe, 1978). The use of replicate samples to overcome patchiness is not a panacea. To detect a change in five species from day to night or location to location would require at least seven replicates. To detect a ten percent difference in numbers of individuals would require ten replicates in a densely populated area and 15 or more in sparsely populated area (Roessler, 1965). Cole (1978b) analyzed catch results from three lake stations along the Michigan shoreline of Lake Erie. He concluded that the intensity of sampling on a given date must be increased at least 100 times (depending on species and time) to reduce permissible error from 50 percent to ten percent of the mean with a 95 percent confidence interval.

When collecting samples with a metered net, as in our lake survey, long oblique tows through the water column are best for reducing the effects of patchiness (McGowan, and Fraundorf, 1966). By making long oblique tows the probability of the net passing through a patch of larvae suspended in the water column is increased. Replicate samples collected by towing a net introduce problems of their own by disturbing the study area by repeated passage of the boat motor and net (Brown and Langford, 1975). In a summary of 13 studies, Weibe and Hollander (1968) demonstrated that a 95 percent confidence interval for a single net tow exceeded one half to two times the observed value.

Pump samplers, generally, can not sample an adequate volume of water to overcome the effects of patchiness. When Kenco pump rates provided by Reutter, *et al.* (1978) are compared with volumes filtered during this survey, one concludes that it would require operating pump samplers three hours to sample the same volume of water as a single three minute net tow.

Sources of variability associated with mechanical problems of metered nets include extrusion of larvae through the mesh, clogging of mesh (Aron, *et al.*, 1965; Taylor, 1953; Winsor and Clark, 1940) and subtle changes in collection technique (Aron and Collard, 1969). Towed nets are selective. Retention of various size larvae and eggs is largely a function of the size and the distortion of the mesh (Vannucci, 1968). A single mesh size can not sample the entire size range of an important species with 100% efficiency (Bowels *et al.*, 1978). For example the size range for rainbow smelt that may be sampled at the same time ranges from 5mm to 20 mm long. Very early life stages are frequently under sampled because of mesh selection due to extrusion of small larvae through the net (Ahlstrom, 1954; Saville, 1959; Lenarz, 1972). Escape of organisms larger than the mesh is aided by the compressibility of the organisms and the flexibility of the net (Vannucci, 1968). Extrusions of larvae through the net can be reduced by decreasing towing speed or reducing mesh size (Quirk, Lawler and Matuskey, 1974). However, if one decreases towing speed active avoidance may increase; finer meshes are more susceptible to clogging.

As a sample tow progresses, organisms and debris become trapped in the meshes of the net, decreasing the amount of water passing through the net. As the tow continues and the degree of clogging increases, the filtering efficiency of the net, i.e. the ability of the net to representatively sample species distribution and composition, continually decreases (Bowles et al., 1978). As the net becomes clogged water passing through the mouth will not be able to pass through the mesh, creating a backwell and pressure wave at the net mouth. This pressure wave at the mouth of the net can sweep larvae not exhibiting an escape response away from the mouth of the net, stimulate active avoidance, and decrease the performance of the flow meter.

Accurate estimates of the amount of water filtered are essential for quantitative ichthyoplankton measurements. Center mounted flow meters tend to register a lower volume of water than is actually filtered (Taylor, 1953). Theoretical calculations of water filtered based on center mounted flow meter are low and generally unreliable (Aron et al., 1965; Taylor, 1953; and Winsor and Clark, 1940).

Changes in net speed and towing depth can produce relatively large changes in the number and size distribution of larvae captured (Aron, 1969). Relatively small changes in boat speed, in spite of careful control of the throttle setting, can introduce a considerable variability in actual net speed and depth, significantly affecting the length frequency distributions of some species in the catch (Aron and Collard, 1969). Nobel (1970) noted this effect to be extreme for yellow perch.

Pump samples have several advantages over metered nets. The effects of clogging and avoidance are greatly reduced. Pumps can provide a more accurate measure of the water volume filtered. However, pumps can not provide adequate sample volumes (unless high volume pumps are used) to overcome variance associated with patchy distribution (Bowles, et al., 1978). Generally, pump sampling in areas such as power plant intake and discharge structures is more quantitative than net sampling because turbulence does not interfere as much as with net performance (Icanberry and Richardson, 1973; Davies and Jensen, 1974). A major disadvantage of using pumps to sample is that a high percentage of larvae become damaged and are then unidentifiable.

No results from successful pipe tap samplers or in-line filters have been reported in the literature (Bowles et al., 1978). Several utilities have discontinued within-plant sampling because of the large number of damaged and extruded organisms. In addition to these problems water velocity through the pipes, even under turbulent conditions, decreases at the boundary near the pipe wall. The particle distribution of larvae within the pipe is affected by the water velocity profile. Thus samples representative of a cross-section of a pipe are difficult to obtain.

Active avoidance of a net is a problem particularly with older, more developed larvae. Hydraulic characteristics of the gear and flow conditions in the vicinity of the gear are the most important factors influencing the accuracy of metered nets (Bowles et al., 1978). Fish are highly sensitive to pressure stimuli (Knight-Jones and Qasin, 1955). Hydrostatic pressure cues from the sampling gear, i.e., turbulence caused

by the towing line and bridles moving through the water or to a pressure wave at the mouth of the net, can stimulate active avoidance in larvae which have developed limited swimming capabilities (Bary et al., 1958; Flemminger and Cluttler, 1965). Brown and Langford (1975) reported that turbulence caused by the movement of the boat motor and the net can decrease the accuracy of replicate samples taken in a single area.

Water turbulence created by pump samplers is much less than that created by moving nets. Therefore active avoidance of pump samplers is much less than that for meter nets, resulting in a more representative length frequency distribution of larvae.

In summary, three sampling methods were used in this study (metered nets, pump samplers, and in-plant line taps). In-plant line taps have never been demonstrated to provide accurate samples. Pump samplers are a good sampling method for areas difficult to sample using nets. If large volumes of water are filtered, pump samples are believed to be more quantitative than those obtained using nets because turbulence does not interfere as much with pump performance (Icanberry and Richardson, 1973). However, a large proportion of larvae obtained using pump samplers are damaged and left unidentifiable. Sampling large volumes of water is relatively easy with metered nets. However active avoidance of older larvae stimulated by water turbulence in front of the net results in an underestimation of density of larger larvae.

WESTERN BASIN, 1975-1976

A total of 19 taxa of larval fish was collected in Ohio and Ontario waters of the Western Basin in 1975 and 1976 (Table 6). The raw data, consisting of the number of larvae at each station for each sampling date can be found in Herdendorf, et al. (1976, 1977), as well as in Heniken, 1977. Yellow perch larvae were identified in samples from four cruises in 1975 and four cruises in 1976. Analysis of yellow perch data indicates concentrations in bottom samples were significantly higher than in surface samples during three of the four sampling periods in 1975 and during two of the four periods in 1976 (Wilcoxin signed rank test, $p < 0.05$). During the period of peak abundance in 1975 and 1976, average yellow perch concentrations were significantly higher in the inshore depth zones than in the shallow offshore reef areas (Wilcoxin rank sum test, $p < 0.05$). With the exception of the first cruise encountering perch larvae in 1975 and the last one in 1976, concentrations of yellow perch inshore samples were higher than concentrations in all offshore samples throughout the period of capture during both years (Wilcoxin rank sum test, $p < 0.20$). For the most part, mean densities were not significantly different in series arbitrarily drawn sectors (A-G) of the study area (Kruskal-Wallis test, $p < 0.05$). An in-depth presentation of perch concentrations within the study area is provided by Patterson (1979).

Emerald shiner and gizzard shad were the most abundant larvae collected. Pro-larval stages of gizzard shad and emerald shiner were rare, post-larvae predominated. The greatest gizzard shad numbers consistently occurred in the highly turbid waters of Maumee estuary and bay and in the Sandusky estuary and bay. Emerald shiner numbers were greatest

in the less turbid, open water portions of the areas sampled. The relative abundance of emerald shiner was different in each of the two years of the study. The large difference served to alter the relative abundance of other species even though estimates of their respective numbers did not change appreciably. No simple explanation of this difference in abundance is apparent at this time. Differential mortality, differential susceptibility to the sampling gear and attendant age factors could affect the relative rankings of the species collected.

Pro-larval smelt were almost entirely lacking in collections. Smelt larvae densities were greatest at open water, offshore sampling stations. Inspection of smelt concentrations and water mass movements lead to the conclusion that smelt in the Western Basin are dispersed by the Detroit River discharge and smelt in the Central Basin are dispersed into the Ohio nearshore zone from spawning areas at Point Pelee and Pelee Island by currents passing through Pelee Passage. Smelt larvae were rarely collected at nearshore sampling points. Walleye larvae were collected at shallow nearshore stations and on offshore reefs. Nearshore distributions of walleye and yellow perch were quite similar. Logperch and white sucker larvae were collected in greatest numbers at nearshore rather than offshore stations. Of particular interest is the finding of larval whitefish on the reefs and in the nearshore area near Locust Point and larval sculpin on the reefs of the island area. Formerly abundant (Trautman, 1957), this study confirms a relict breeding populations of each is extant in the Western Basin.

It is likely that some species with very small pro-larval stages were not collected and the abundance of others with relatively small larval stages were underestimated due to the relatively large mesh nets used to collect samples in 1975 and 1976. It is reasonable to assume that post-larval stages were effectively samples. Larval stages were determined using the definitions of Hubbs (1942). Selected species were also determined using the definitions of Snyder and Snyder (1978). Lengths and stages are provided in Appendix A.

MAUMEE AND SANDUSKY RIVER ESTUARIES, 1975-1977

The results of this three-year sampling effort are summarized in Tables 7 and 8. A total of 17 taxa of larval fish are reported from the Maumee River estuary and 11 taxa from the Sandusky estuary. The raw data consisting of number of larvae at each station for each sampling date can be found in Bartholomew (1979); Herdendorf (1977); Herdendorf and Cooper (1975 and 1976); Herdendorf, Cooper, Heniken and Snyder (1976 and 1977); Reutter, Herdendorf and Sturm (1978a and 1978b and Snyder (1978). Gizzard shad, white bass and freshwater drum composed 98 percent of the fish larvae collected each year in the Maumee River estuary. These species constituted approximately 91 percent of the larvae collected during the study of the Sandusky River estuary. Snyder's (1978) investigation of larvae in the riffle areas above the estuaries proper indicated a greater abundance of carp larvae in the riffle areas. This indicated greater carp larvae densities in littoral areas and may have resulted in an overall underestimate of their abundance in the study areas. The abundance and period of occurrence of larval fish species distributed predominantly in the littoral zone, e.g., sunfish, crappie, catfish, madtoms, were

similarly underestimated. The abbreviated sampling period in 1976 probably resulted in an underestimate of the relative abundance of species, freshwater drum in particular, exhibiting period of peak abundance which extend beyond the limits of the sampling periods in 1976.

During periods of high densities (>100 larvae/100 m³), Snyder found significantly (ANOVA, $p < 0.05$) more larval gizzard shad and white bass in sheltered low flow portions than in the mid-channel portion of the mid-estuary sampling location. The predominate number of rainbow smelt and yellow perch larvae were collected at the Maumee River mouth location. Very limited numbers of yellow perch and no rainbow smelt were collected further upstream; neither species were collected in the Sandusky River estuary. It is suggested that lake water intruding into the lower portion of the estuary carried lake spawned yellow perch and rainbow smelt larvae to the river mouth location (Bartholomew, 1979; Reutter, *et al.*, 1978a, b; Snyder, 1978).

Larval walleyes were of particular interest. Walleye larvae ranked fourth, fifth and sixth in each respective year of the study in the Maumee River estuary and ranked sixth among all larvae captured in the Sandusky River estuary. The average density of larvae throughout the study ranged from less than 1.0 to 3.5/100 m³. Snyder analyzed egg and larvae counts from samples taken in the riffle areas. The results indicate a patchy, or nonrandom, distribution of walleye eggs (χ^2 dispersion test) while larvae were randomly (Poisson) distributed. Bartholomew found no significant differences (Wilcoxin signed rank tests, $p < 0.05$) between numbers of larval yellow perch and walleye in surface and bottom samples collected at the mid-estuary and lower estuary locations. Similar analyses at the river mouth location revealed significant ($p < 0.05$) differences in larval walleye but no in yellow perch numbers. Larval walleye were apparently located in near-bottom areas at this location. The effect of lake water intrusion on walleye distribution at the river mouth location was not determined. Overall, larval walleye densities decrease from relatively high densities upstream to relatively low densities downstream.

Calculations by Snyder (1978) indicated that the Maumee estuary produced larger numbers of individuals of all larval species than did the Sandusky estuary although higher densities of walleye and logperch larvae were recorded in the Sandusky estuary. Approximately 100 times more gizzard shad larvae were estimated in the Maumee than the Sandusky estuary. White bass larvae were collected almost exclusively in the estuaries, at river mouths and in Maumee and Sandusky bays. The tributaries of the Western and Central Basins seem to be the primary white bass spawning areas. The bays may serve as nursery grounds for post-larvae and juveniles. The greatest numbers of freshwater drum were collected in the same, highly turbid areas.

The combined volumes of the Maumee and Sandusky estuaries are less than two percent of the Western Basin study area. Comparison of similar sampling dates indicates the estimated number of larvae in the Maumee estuary was equal to that of the Western Basin study area. On a fish per volume basis, the Maumee estuary contained more gizzard shad, white bass, logperch, walleye and freshwater drum than the Western Basin study area on many sampling dates.

TABLE 6. PERIOD OF CAPTURE AND RELATIVE ABUNDANCE OF LARVAL FISH IN THE OHIO WATERS OF THE WESTERN BASIN OF LAKE ERIE DURING 1975 AND 1976

SPECIES	FIRST CAPTURE		LAST CAPTURE		PEAK ABUNDANCE	RELATIVE ABUNDANCE ^a	
	1975	1976	1975	1976		1975	1976
Gizzard Shad/Alewife	24 May	30 April	3 Sept.	3 Sept.	June - Mid-July	40%(1)	17%(2)
Lake Whitefish	--	12 April	--	30 April	Late April	--	<0.1%
Rainbow Smelt	13 May	10 May	13 July	21 June	Mid - Late May	7%(5)	7%(3)
Mooneye	22 May	--	22 May	--	Late May	<0.1%	--
Carp/Goldfish	23 May	30 May	4 Aug.	28 July	Mid- Late June	2%(7)	0.6%(8)
Emerald Shiner	22 May	22 June	3 Sept.	3 Sept.	Mid-June - Early Aug.	16%(3)	62%(1)
Spottail Shiner	22 May	23 May	2 July	2 July	Early - Mid-June	2%(8)	2.7%(6)
Quillback Carpsucker	1 June	23 May	17 June	23 May	Early - Mid-June	<0.1%	<0.1%
White Sucker	22 May	30 April	22 May	30 May	Mid - Late May	<0.1%	<0.1%
Troutperch	--	23 May	--	23 May	Late May	--	<0.1%
White Bass/White Perch	22 May	23 April	15 July	4 Aug.	Early - Mid-June	2%(6)	0.1%(10)
Sunfish (<i>Lepomis</i> spp.)	21 June	22 June	15 July	28 July	Early - Mid-July	<0.1%	<0.1%
Smallmouth Bass	11 June	--	11 June	--	Early June	<0.1%	--
Crappie (<i>Pomoxis</i> spp.)	1 June	7 June	4 Aug.	3 Sept.	Late June - Early July	<0.1%	<0.1%
Yellow Perch	12 May	23 April	23 June	7 July	Early May - Early June	12%(4)	5.8%(4)
Logperch Darter	11 June	7 June	3 July	16 July	Mid-June	<0.1%	<0.1%(9)
Walleye	22 May	21 April	22 May	22 May	Late April - Early May	<0.1%	0.8%(7)
Freshwater Drum	22 May	7 June	4 Aug.	5 Aug.	Early - Late June	19%(2)	4%(5)
Sculpin (<i>Cottus</i> sp.)	--	30 April	--	22 May	Early May	--	<0.1%

^aNumbers enclosed parenthetically indicate relative rank

TABLE 7. LIMNETIC FISH LARVAE FROM THE MAUMEE RIVER ESTUARY, 1975-1977.

SPECIES	First Capture				Last Capture		Period of Peak Abundance 3 year Summary	Avg. Density No./100m ³ 1976	Relative Abundance ²			Avg. Density No./100m ³ 1977
	1975	1976	1977		1975	1976			1975	1976	1977	
Gizzard Shad/ Alewife	15 May	23 Apr	7 May	25 Aug	8 June	25 Aug	Late May-Early June	355	495(1)	895(1)	775(1)	278
Rainbow Smelt	25 June	7 May	7 May	24 July	8 June	28 July	---	<1	0.65(5)	<0.15(9)	<0.15(14)	<1
Carp/Goldfish	15 May	21 Apr	24 Apr	5 Aug	8 June	25 Aug	Late May	14	<0.15(8)	45(3)	0.25(6)	<1
Emerald Shiner	25 June	---	4 June	25 Aug	---	18 Aug	Late July	---	0.35(7)	---	0.15(8)	<1
Spottail Shiner	---	28 May	23 May	---	---	11 Aug	---	<1	---	---	<0.15(10)	<1
Quillback	---	---	7 May	---	---	7 May	---	---	---	---	<0.15(15)	<1
White Sucker	15 May	21 Apr	25 Apr	15 May	8 June	11 May	Early May	1	<0.15	0.15(8)	<0.15(11)	<1
Channel Catfish	8 July	---	27 May	24 July	---	11 Aug	---	---	<0.15(10)	---	<0.15(13)	<1
Madtom (Noturus sp.)	24 July	---	7 July	24 July	---	14 July	---	---	<0.15	---	<0.15(17)	<1
Troutperch	---	---	15 May	---	---	15 May	---	---	---	---	<0.15(16)	<1
White Bass/ White Perch	15 May	27 Apr	14 May	24 July	8 June	4 Aug	Late May-Early June	24	35(3)	65(2)	75(3)	79
Sunfish (Lepomis spp.)	8 July	---	24 May	25 Aug	---	28 July	---	---	<0.15(9)	---	15(4)	2
pie omoxis spp.)	---	---	31 May	---	---	11 Aug	---	---	---	<0.15(10)	<15(9)	<1
Yellow Perch	15 May	23 Apr	30 Apr	5 Aug	8 June	25 Aug	Mid-May-Early June	3	0.65(4)	0.15(6)	0.35(5)	1
Walleye	15 May	8 Apr	16 Apr	15 May	20 May	15 May	Mid-Late April	<1	0.45(6)	0.15(5)	0.25(7)	3.5
Logperch	6 June	23 Apr	25 Apr	6 June	27 May	7 July	Mid-Late May	1	<0.15	0.15(7)	<15(12)	<1
Freshwater Drum	6 June	25 May	11 May	5 Aug	8 June	1 Sept	Early June	4	465(2)	0.45(4)	145(2)	60

¹Truncated sampling period in 1976 (7 April to 8 June)²Relative rank indicated parenthetically

TABLE 8. LIMNETIC FISH LARVAE FROM THE SANDUSKY RIVER ESTUARY, 1976.

SPECIES	First Capture 1976	Last Capture 1976 ¹	Period of Peak Abundance	Relative Abundance ² 1976	Avg. Density No./100m ³
Gizzard Shad/Alewife	26 April	7 June	---	80%(1)	61
Carp/Goldfish	22 April	7 June	---	3%(4)	36
White Sucker	26 April	31 May	Mid-May	0.3%(7)	1
Sucker (<i>Catostomidae</i> sp.)	19 May	19 May	Mid-May	<0.1%	--
Troutperch	2 June	2 June	---	0.3%(8)	--
White Bass/White Perch	26 April	7 June	---	11%(2)	10
Sunfish (<i>Lepomis</i> spp.)	3 May	3 May	---	<0.1%	--
Crappie (<i>Pomoxis</i> spp.)	26 May	26 May	---	<0.1%	--
Walleye	12 April	3 May	Late April	0.6%(6)	1
Logperch	22 April	7 June	---	4%(3)	4
Freshwater Drum	26 May	7 June	---	0.7%(5)	7

¹Truncated sampling period (12 April to 7 June)²Relative rank indicated parenthetically

WESTERN BASIN, 1977

An intensive survey of the nearshore zone of the Western Basin in 1977 resulted in the collection of 20 taxa of larval fishes. Sixteen species were identified, representing 10 families and comprising 99.05% of the catch. The other 0.05% of the catch was identified to the genus or family level.

Ten species, gizzard shad, yellow perch, emerald shiner, white bass, carp, freshwater drum, log perch, walleye, rainbow smelt and spottail shiner were collected in numbers great enough to be considered abundant (i.e., average basin-wide density $0.10/100\text{ m}^3$). Four species, gizzard shad, yellow perch, emerald shiner, and white bass made up over 97% of the catch, with gizzard shad alone accounting for 87% of the total catch. The other 10 taxa were represented by a few or sometimes only a single specimen. Table 9 lists the average density for the entire sampling period and percentage of the total catch represented by each taxon for the entire nearshore zone of the Western Basin.

Seventeen taxa of larval fishes were captured along the Michigan shoreline from Stoney Point to Woodtick Peninsula. Eleven taxa, gizzard shad, emerald shiner, yellow perch, carp, white bass, log perch, rainbow smelt, freshwater drum, walleye, spottail shiner, and sunfish *Lepomis* spp. were abundant. Five species, gizzard shad, emerald shiner, yellow perch, carp, and white bass made up 98.5% of the catch. Whitefish larvae, although rare, were captured on April 29th along the entire Michigan shoreline. Whitefish densities were greatest at Station M2 where the average density of larvae was found to be 9103 per 100 m^3 (see Figure 6 for station location). Table 10 lists the average density for the entire sampling period and the percentage of the total catch represented by each taxon of larvae collected along the Michigan shoreline.

Samples collected in Maumee Bay contained a total of 18 taxa of larval fishes. Gizzard shad, white bass, yellow perch, emerald shiner, freshwater drum, rainbow smelt, carp, log perch, walleye, and spottail shiner larvae were found to be abundant. Three species, gizzard shad, white bass, and yellow perch made up over 97.5% of the catch with gizzard shad larvae representing 90.58% of the total larvae catch. Sauger larvae were captured on May 12 and on June 3 at two locations, MB2/2 and MB1/2. Table 11 lists the average density for the entire sampling period and the percentage of the total catch represented by each taxon of larvae collected in Maumee Bay.

Fifteen taxa were collected during our sampling effort along the Ohio shoreline of the Western Basin. Again gizzard shad yellow perch, emerald shiner, white bass, walleye, freshwater drum, log perch, carp, smelt, and spottail shiner were abundant. Game fish, yellow perch, white bass and walleye contributed to 13.8% of the total larvae captured. Whitefish larvae were found in a single sample collected on April 29 at Station OH3/1 (see Figure 6 for station location). Table 12 lists the average density for the entire sampling period and the percentage of the total catch represented by each taxon of larvae collected along the Ohio shoreline.

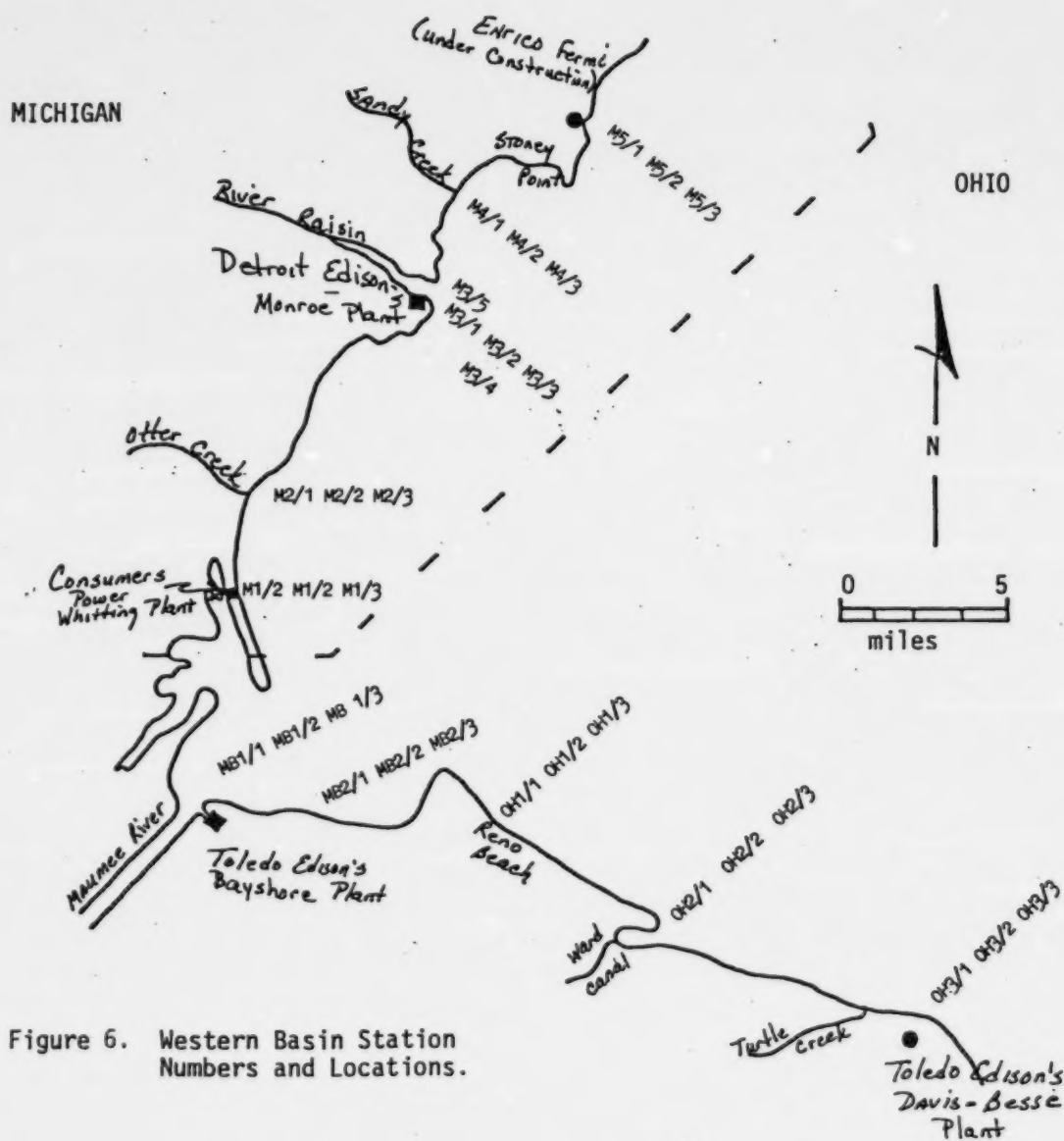


Figure 6. Western Basin Station Numbers and Locations.

TABLE 9. RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED IN
THE WESTERN BASIN OF LAKE ERIE IN 1977

SPECIES	AVERAGE DENSITY ¹ (# larvae/100m ³)	PERCENT ² OF CATCH
Gizzard Shad/Alewife	266.16	82.58
Yellow Perch	21.31	6.61
Emerald Shiner	18.72	5.81
White Bass	7.85	2.44
Carp	2.82	0.88
Freshwater Drum	1.76	0.55
Log Perch	1.43	0.44
Walleye	0.99	0.31
Rainbow Smelt	0.88	0.28
Spottail Shiner	0.18	0.06
Unidentified Sunfish (<u>Lepomis</u> spp.)	0.05	0.02
Whitefish	0.04	0.01
Unidentified <u>Cyprinidae</u> spp.	0.03	0.01
White Sucker	0.02	<0.01
Quillback Carpsucker	0.02	<0.01
Channel Catfish	0.01	<0.01
Trout Perch	0.01	<0.01
Sauger	0.01	<0.01
Unidentified <u>Percidae</u> spp.	<0.01	<0.01
Unidentified Crappie (<u>Pomoxis</u> spp.)	<0.01	<0.01
TOTAL	322.30	

¹Average densities found by dividing the sum of the calculated densities by the number of tows taken during period of larval occurrence.

²Species ranked according to descending percent of catch.

TABLE 10. RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED ALONG THE MICHIGAN SHORELINE FROM STONEY POINT TO WOODTICK PENINSULA IN 1977

SPECIES	AVERAGE DENSITY ¹ (# larvae/100 m ³)	PERCENT ² OF CATCH
Gizzard Shad/Alewife	193.82	75.00
Emerald Shiner	31.98	12.38
Yellow Perch	21.07	8.15
Carp	4.77	1.85
White Bass	3.02	1.17
Log Perch	2.00	0.76
Rainbow Smelt	0.63	0.24
Freshwater Drum	0.50	0.19
Walleye	0.21	0.08
Spottail Shiner	0.12	0.04
Unidentified Sunfish (<u>Lepomis</u> spp.)	0.11	0.04
Whitefish	0.09	0.04
Unidentified <u>Cyprinidae</u> spp.	0.06	0.02
White Sucker	0.01	< 0.01
Trout Perch	0.01	< 0.01
Channel Catfish	0.01	< 0.01
Unidentified Crappie (<u>Pomoxis</u> spp.)	0.01	< 0.01
TOTAL	258.42	

¹Average density found by dividing the sum of the calculated densities by the number of tows taken during period of larval occurrence.

²Species ranked according to descending percent of catch.

TABLE 11. RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED
IN MAUMEE BAY IN 1977

SPECIES	AVERAGE DENSITY (# larvae/100m ³)	PERCENT ² OF CATCH
Gizzard Shad/Alewife	541.80	90.58
White Bass	23.32	3.99
Yellow Perch	17.84	2.98
Emerald Shiner	5.57	0.93
Freshwater Drum	5.07	0.85
Rainbow Smelt	2.00	0.34
Carp	1.22	0.21
Log Perch	0.74	0.12
Walleye	0.30	0.05
Spottail Shiner	0.16	0.03
Sauger	0.05	<0.01
Unidentified	0.05	<0.01
Quillback Carpsucker	0.02	<0.01
Unidentified <u>Cyprinidae</u> spp.	0.02	0.01
Channel Catfish	0.01	<0.01
Unidentified <u>Percidae</u> spp.	0.01	<0.01
Unidentified Sunfish (<u>Lepomis</u> spp.)	0.01	<0.01
Trout Perch	0.01	0.01
TOTAL	598.18	

¹Average density found by dividing the sum of the calculated densities by the number of tows made during the period of larval occurrence.

²Species ranked according to descending order of percent of catch.

TABLE 12. RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED ALONG THE OHIO SHORELINE BETWEEN LITTLE CEDAR POINT AND LOCUST POINT IN 1977

SPECIES	AVERAGE DENSITY ¹ (#larvae/100m ³)	PERCENT OF CATCH
Gizzard Shad/Alewife	183.26	81.27
Yellow Perch	24.19	10.65
Emerald Shiner	6.97	3.07
White Bass	4.50	1.99
Walleye	2.72	1.18
Freshwater Drum	1.35	0.60
Log Perch	1.04	0.45
Carp	0.85	0.37
Smelt	0.54	0.24
Spottail Shiner	0.25	0.11
Whitefish	0.05	0.02
Unidentified Crappie (<i>Pomoxis</i> spp.)	<0.02	<0.01
Channel Catfish	<0.01	<0.01
Trout Perch	0.01	<0.01
Quillback Carpsucker	0.01	<0.01
TOTAL	231.20	

¹Average densities found by dividing the sum of the calculated densities by the number of tows made during the period of larval abundance.

²Species ranked according to descending percent of catch.

TABLE 13. VOLUME WEIGHTED ESTIMATES OF LARVAL FISHES IN THE WESTERN BASIN (1977)

Species	Volume Weighted Total	Percent of Total Production ¹
Gizzard Shad/Alewife	1.03×10^9	79.24
Yellow Perch	1.35×10^8	10.38
Emerald Shiner	5.16×10^8	3.97
White Bass	2.65×10^8	2.04
Carp	1.64×10^8	1.26
Freshwater Drum	1.42×10^7	1.09
Log Perch	6.82×10^7	0.52
Rainbow Smelt	6.34×10^7	0.49
Walleye	6.08×10^7	0.47
Spottail Shiner	1.27×10^6	0.10
Whitefish	2.32×10^6	0.02
Sauger	2.25×10^6	0.02
<u>Pomoxis</u> sp.	1.63×10^5	0.01
Unidentifiable	1.36×10^5	<0.01
White Sucker	1.28×10^5	<0.01
<u>Lepomis</u> sp.	1.12×10^5	<0.01
Quillback Carpsucker	7.65×10^5	<0.01
Cyprinidae	6.70×10^5	<0.01
Channel Catfish	6.69×10^5	<0.01
Trout Perch	3.83×10^5	<0.01
Percidae	2.66×10^5	<0.01

¹Species ranked in descending order of production.

Volume weighted estimates of total species abundance were calculated to give an indication of larvae production in the nearshore zone in 1977. The estimates as presented in Table 13 are believed to be much lower than what is actually true. Based on the assumption that sampling once every ten days assures each larval cohort will be vulnerable to the sampling gear once, it is probable that two or possibly three cohorts were not sampled because of a combination of equipment failure and inclement weather. Volume weighted estimates calculated for each depth zone during each sampling period are available in Appendix B.

A detailed description of the spatial and temporal distributions of the ten most abundant larval species captured in the Western Basin follows.

Clupeids (Gizzard shad and Alewife)

With a basin-wide mean density of 266.16 larvae per 100 m³, clupeid larvae were the most abundant larval fish species captured at all stations in the Western Basin in 1977. Clupeid were first collected on May 22 and were found in large numbers in every sample collected during the remainder of the sampling season. Clupeid larvae were most abundant in samples collected on June 4 with a mean basin-wide density of 803 larvae per 100 m³. Figure 7 shows the mean density of gizzard shad larvae on each sampling date summed over all stations.

Figure 8 displays the mean number of larvae captured at each station summed over all sampling periods. The Kruskal-Wallis test was used to test for significant differences between the three physiographic areas, i.e. the Michigan shoreline, Maumee Bay, and the Ohio shoreline. No significant differences in larval densities could be detected ($\alpha = .05$). Friedman's Rank Sum Test was conducted to test for differences between transects, with stations being replicate samples. Statistical differences ($\alpha = .01$, $df=9$) were detected between areas of highest, the M2 and MB1 transects, and lowest densities, the M4, M5 and OH3 transects. Friedman's test was also used to test for differences between depth zones, with transects being replicate samples. Statistical differences were detectable ($\alpha = .01$, $df=2$) between the first and second depth zones. No significant differences were detectable between depth zones one and three or depth zones two and three. Highest densities sampled were on June 4 at Station MB1/1, 4983 larvae per 100 m³, and 2674 larvae per 100 m³ on June 12 at Station M2/1.

Rainbow Smelt

With a basin-wide mean density of 0.88 larvae per 100 m³, smelt larvae were the ninth most abundant species collected. Smelt larvae were first collected on May 22 and were collected during every sampling effort thereafter. The samples collected indicate smelt densities were highest in the Western Basin on June 6, with a basin-wide mean density of 2.98 larvae per 100 m³ (Figure 9).

No statistical differences in densities of larvae were detectable between the three physiographic areas (Kruskal-Wallis, $\alpha = .05$), nor were statistical differences in densities detectable between transects (Friedman's Rank Sum, $\alpha = .05$, $df=9$). Statistical differences were

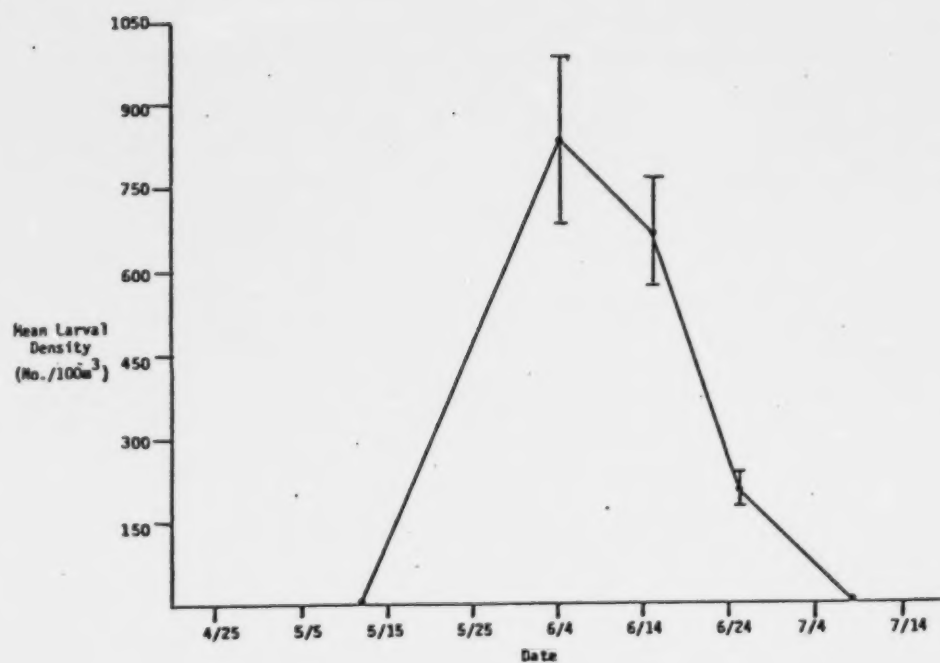


Figure 7. Mean Density of Clupeid Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

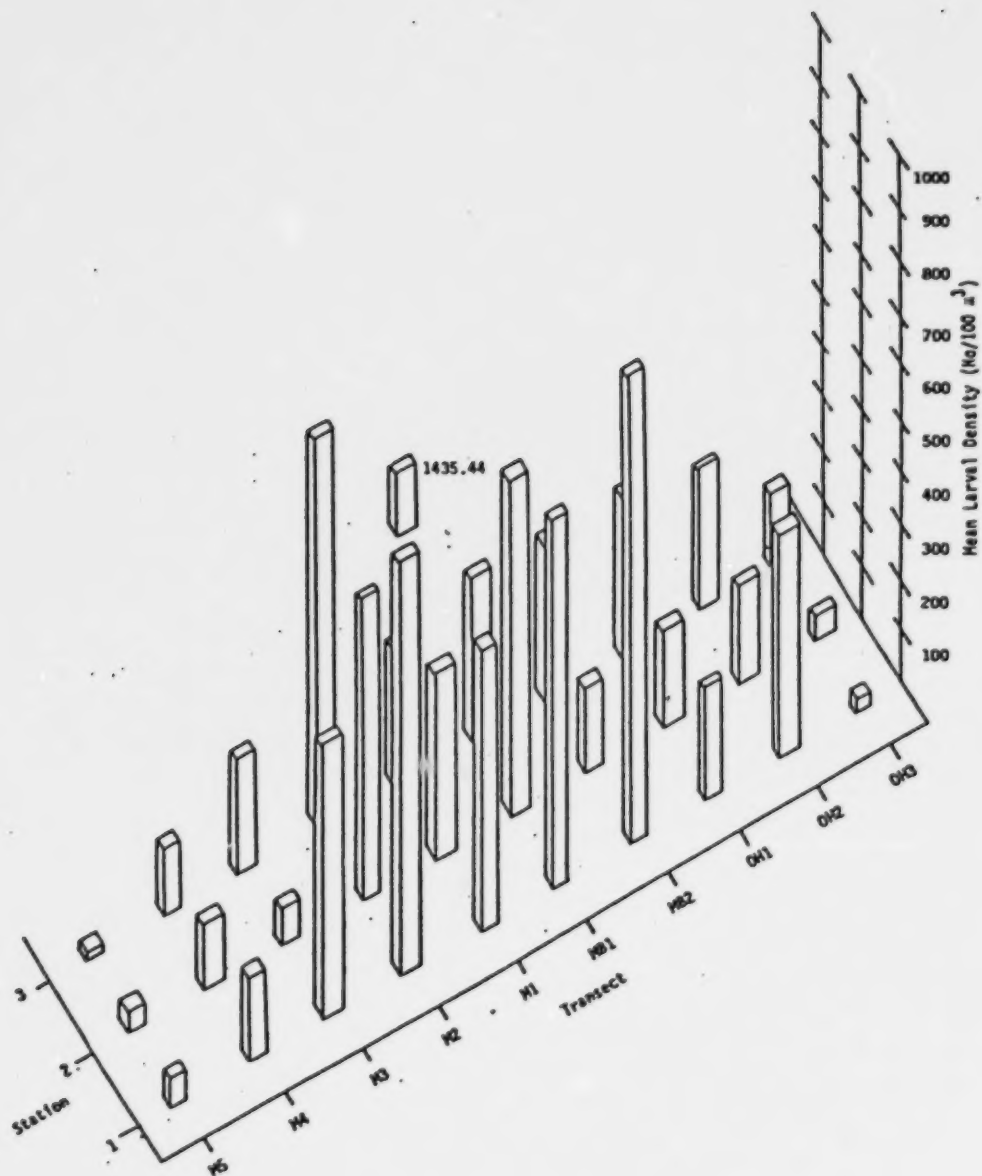


Figure 8. Western Basin - 1977.
Mean Density of Clupeid Larvae at Each Station.

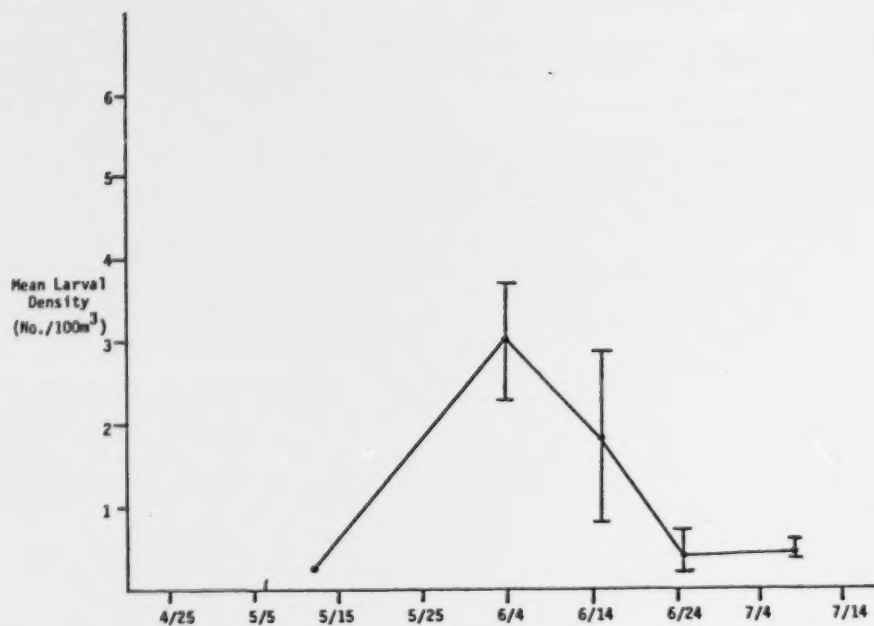


Figure 9. Mean Density of Smelt Larvae in the Western Basin During 1977.
Distance between bars represents one standard error of the mean.

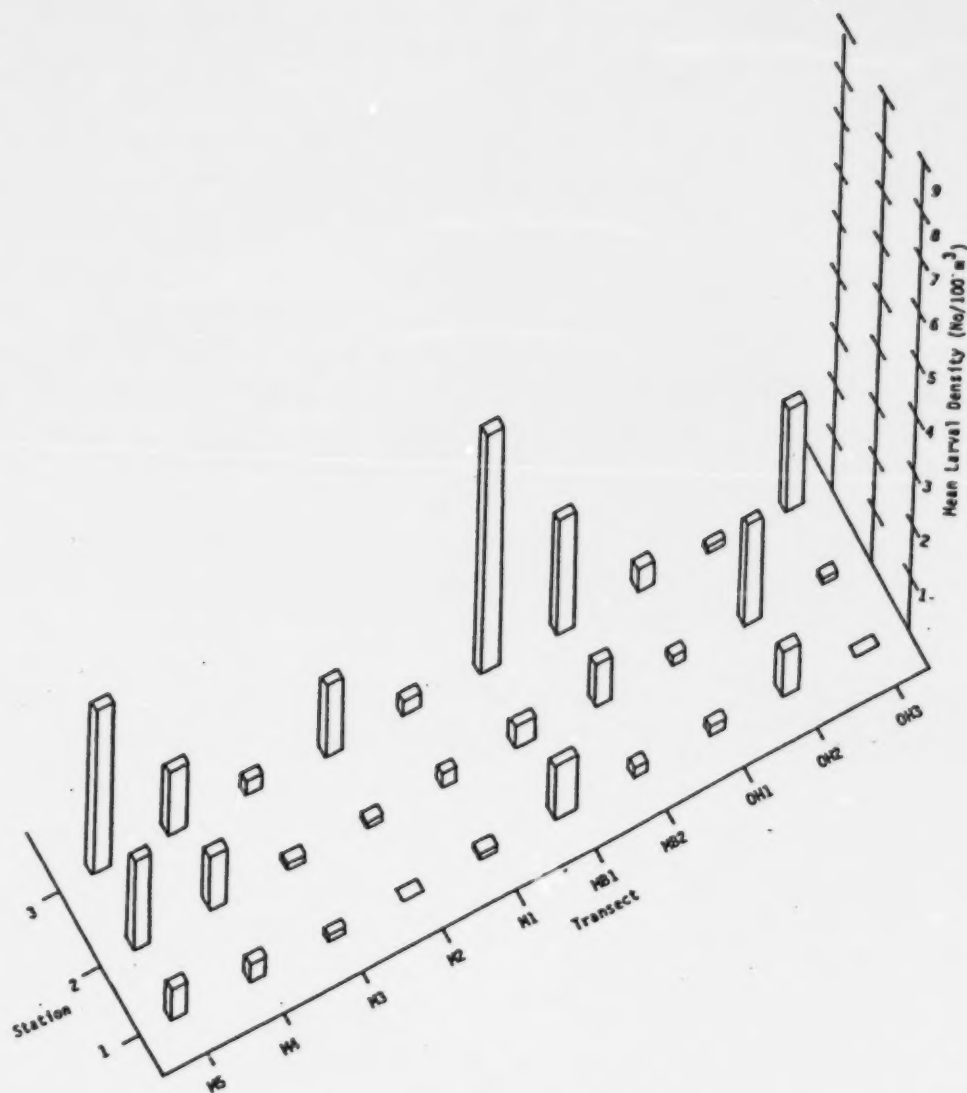


Figure 10. Western Basin - 1977.
Mean Density of Smelt Larvae at Each Station.

detectable between larvae densities in the onshore and offshore depth zones. With higher densities of smelt larvae being found offshore, 65% of the total number of smelt were captured offshore. Generally smelt densities were highest in Maumee Bay and the two northern-most Michigan transects, M4 and M5, where 43% and 27%, respectively, of the total smelt catch was made (Figure 10). Highest density of smelt larvae occurred at Station MB1/3, 54.5 larvae per 100 m³.

Carp/Goldfish and Hybrids

With a mean basin-wide density of 2.82 larvae per 100 m³, carp larvae were the fifth most abundant species captured in the Western Basin in 1977. Carp larvae were first captured on May 5 and were collected during each sampling effort thereafter. Carp larvae were most abundant in our samples collected on June 4 with a basin-wide larval density of 9.7 larvae per 100 m³ (Figure 11).

No statistical differences were detectable between densities in Maumee Bay, the Michigan or the Ohio shorelines (Kruskal-Wallis $\alpha=.05$), nor were statistical differences detectable between transects (Friedman's Rank Sum $\alpha=.05$, $df=9$) or between depth zones (Friedman's Rank Sum $\alpha=.05$, $df=2$). Highest densities of carp larvae were captured on June 14, at Stations M1/2, (499 larvae per 100 m³), and M3/1, (419 larvae per 100 m³). No carp larvae were captured at Stations MB1 and OH3 (Figure 12).

Emerald Shiner

Emerald shiner, with an average basin-wide density of 18.72 larvae per 100 m³ were the third most abundant species of larval fish captured. Emerald shiner larvae were first captured on June 4 and were captured during every sampling effort thereafter. Samples collected indicated larval emerald shiner reached a maximum basin-wide density of 101 larvae per 100 m³ on June 22 (Figure 13).

Statistical tests indicated there were no differences in densities between physiographic areas, transects, or stations. However, looking at the distribution of emerald shiner larvae in Figure 14, the majority of larvae were captured along transects M4 (33% of the total catch) and M5 (31% of the total catch), and in the first depth zone where 50% of the total number of emerald shiner were captured. Highest densities of emerald shiner, 1432 larvae per 100 m³, occurred at Station M5/1 on June 22.

Spottail Shiner

With a basin-wide mean density of 0.18 larvae per 100 m³ spottail shiner were ranked tenth in abundance of larval fishes captured in 1977. Spottail shiner were first captured on June 4 and were captured during each sampling effort for the remainder of the sampling season. Samples indicated larval spottails were in greatest abundance on June 4 with a basin-wide mean density of 0.49 larvae per 100 m³ (Figure 15).

Although 59% of the spottail catch was made along transects M4 and M5, no statistical differences in density could be detected between physiographic areas or between transects. Friedman's Rank Sum Test ($\alpha=.05$, $df=2$)

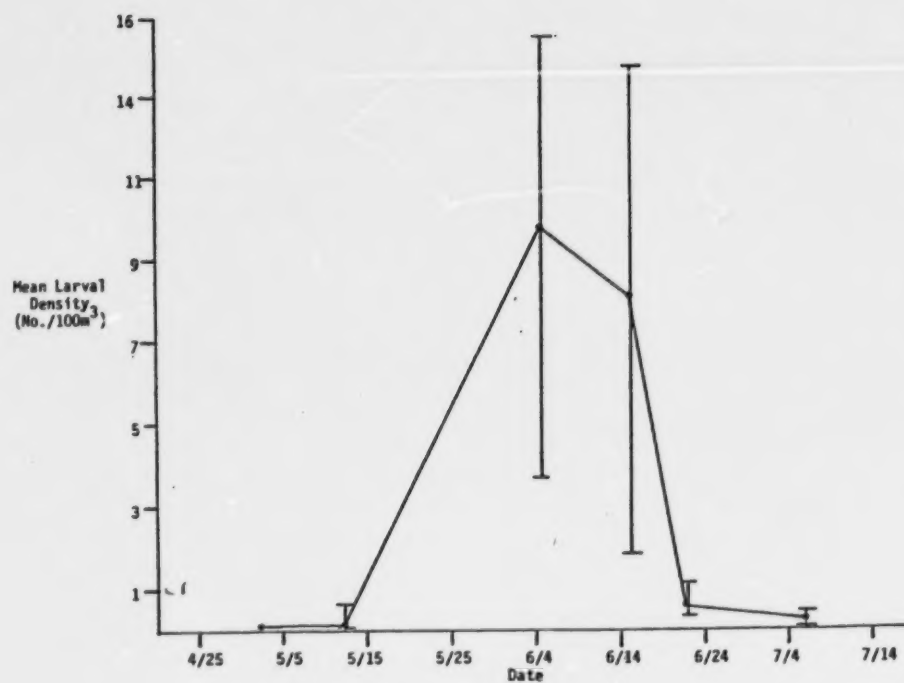


Figure 11. Mean Density of Carp Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

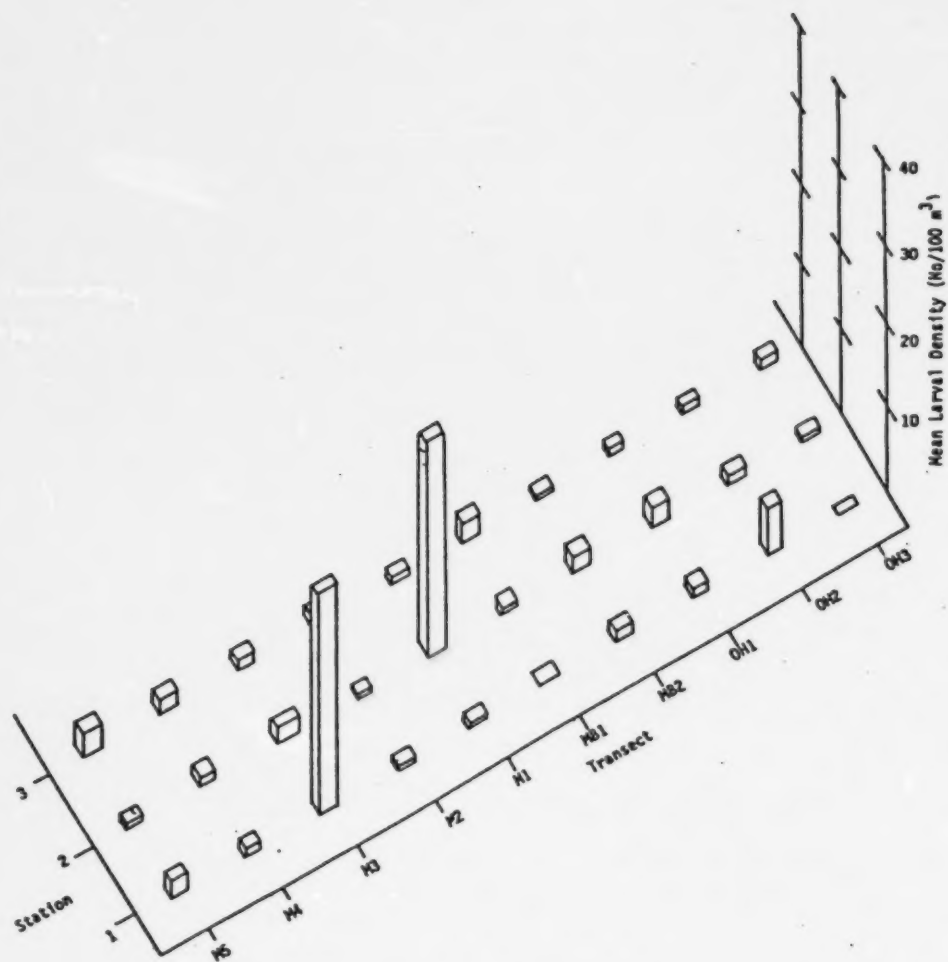


Figure 12. Western Basin - 1977.
Mean Density of Carp Larvae at Each Station.

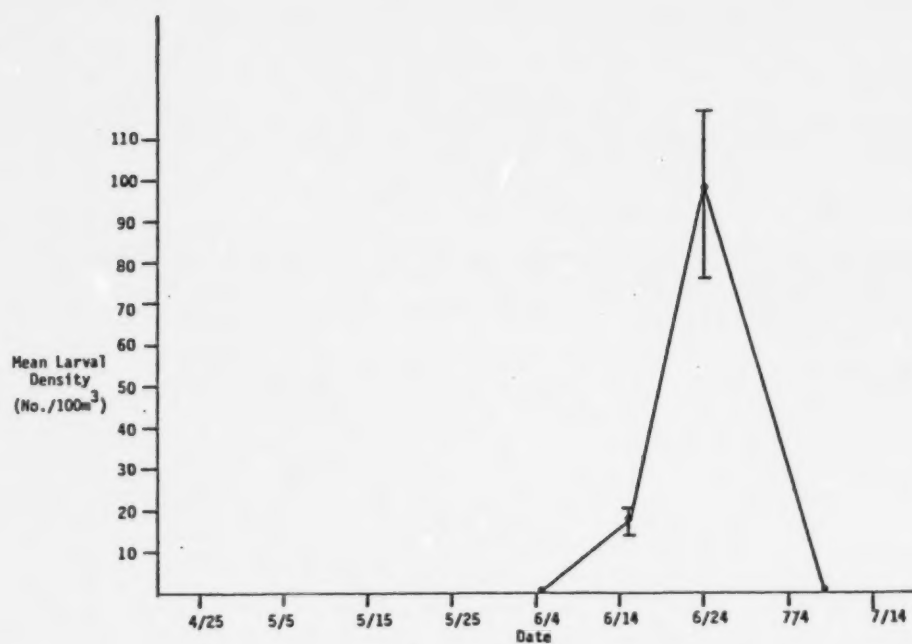


Figure 13. Mean Density of Emerald Shiner Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

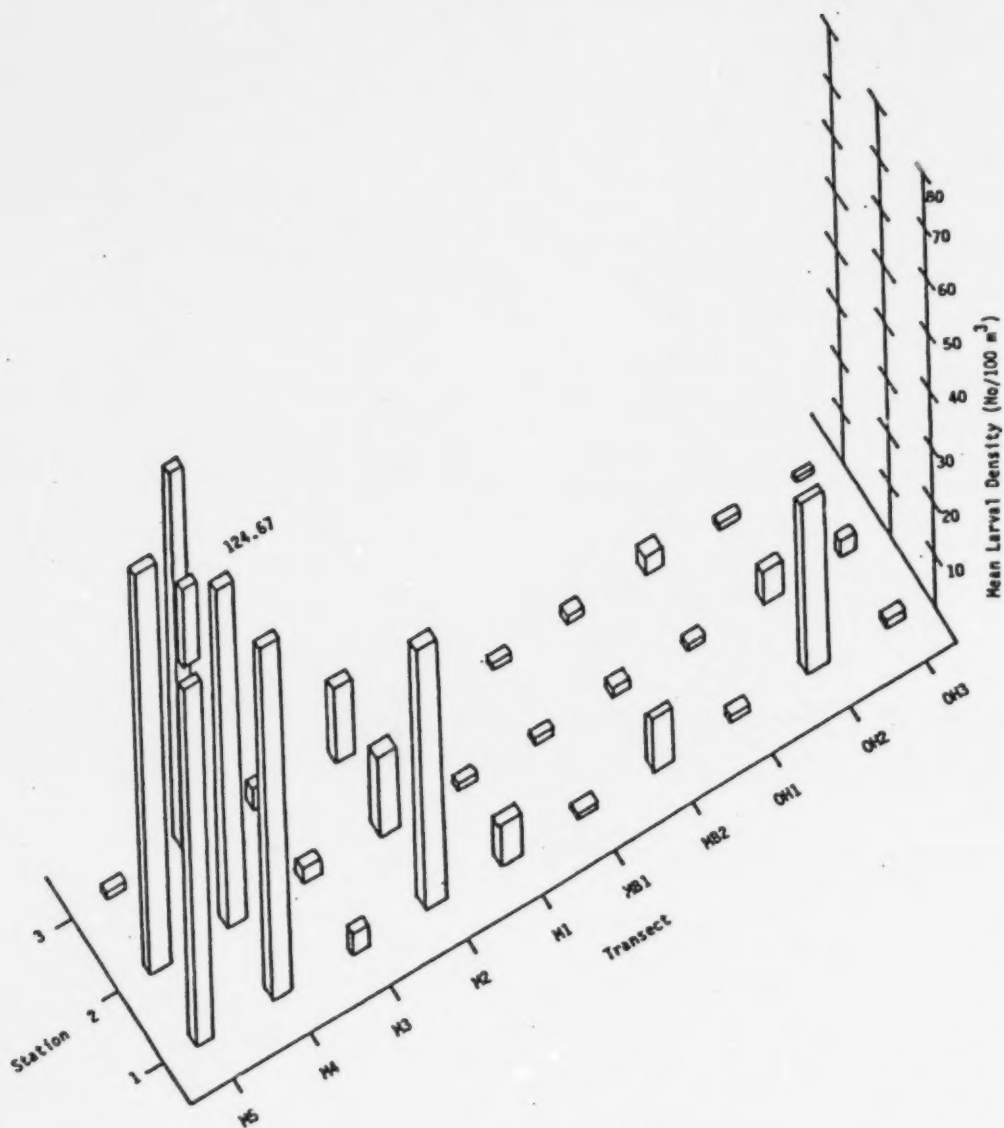


Figure 14. Western Basin - 1977.
Mean Density of Emerald Shiner Larvae at Each
Station.

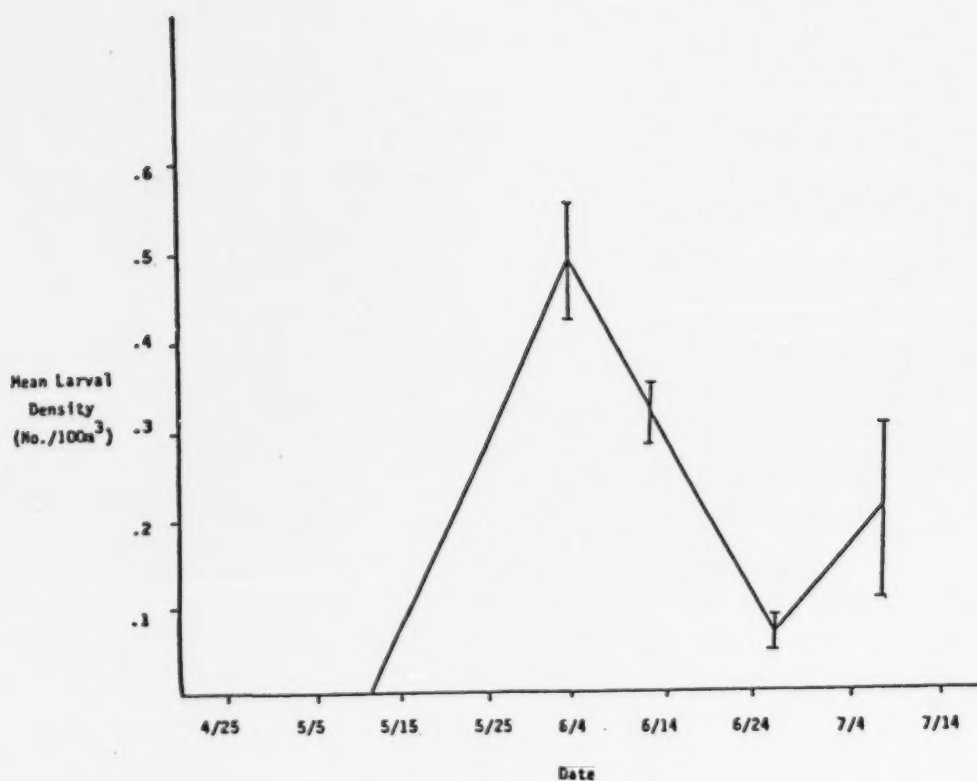


Figure 15. Mean Density of Spottail Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

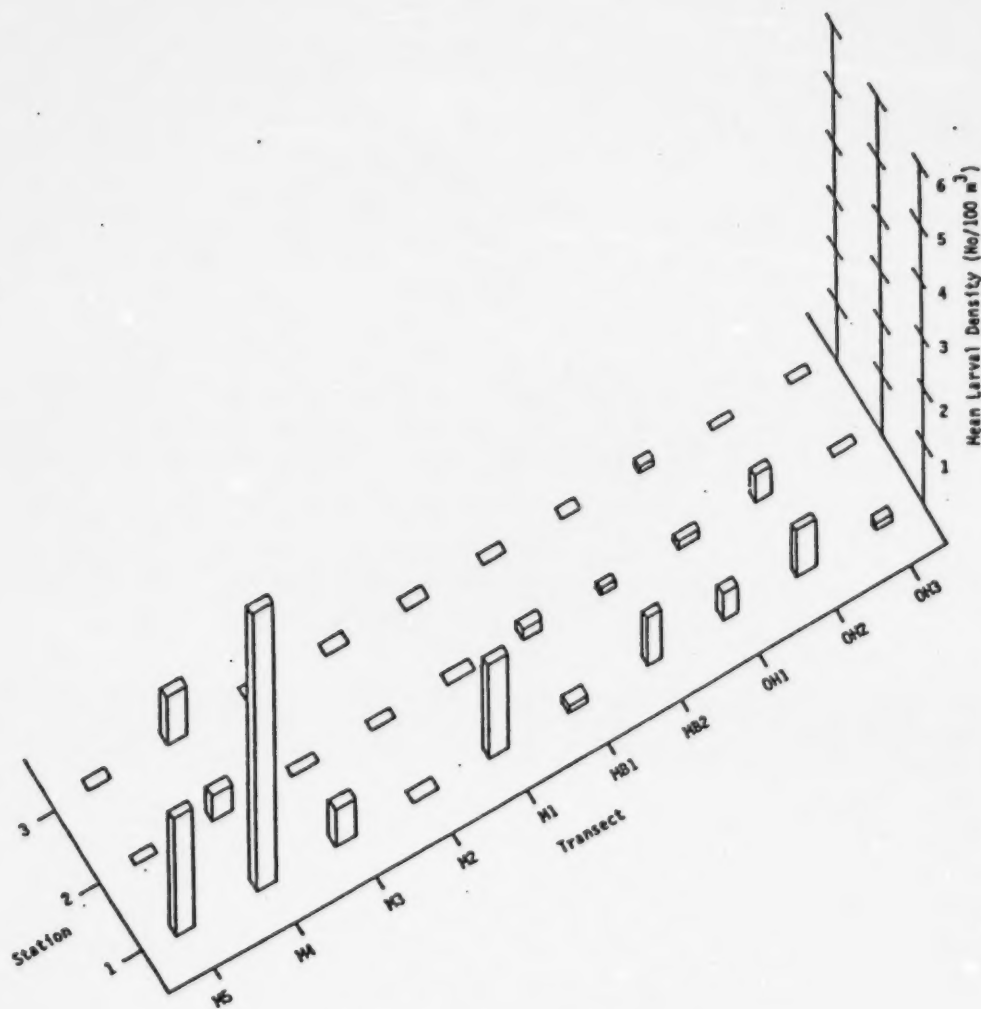


Figure 16. Western Basin - 1977.
Mean Density of Spottail Shiner Larvae at
Each Station.

indicated significantly higher densities of spottails were found in the nearshore zone than offshore (81.4% of the total spottail catch was made in depth zone 1). Maximum density of spottail shiner sampled was 5.02 larvae per 100 m³ at Station M4/1 on June 13 (Figure 16).

White Bass

With a basin-wide mean density of 7.85 larva per m³, white bass were the fourth most abundant species captured in this study. White bass were first collected on May 22 and were collected during every sampling effort thereafter. Samples collected indicated peak densities of 29.5 white bass larvae per 100 m³ occurred on June 13 (Figure 17).

Densities of larval white bass were found to be significantly greater in Maumee Bay than along either the Michigan or Ohio shorelines. Sixty-three percent of the total white bass catch was found in Maumee Bay (Kruskal-Wallis $\alpha=.05$). Friedman's Rank Sum Test ($\alpha=.01$) indicated lowest densities of white bass larvae were sampled at OH3 and M5 (Figure 18). No significant differences were detected between depth zones (Friedman's Rank Sum Test $\alpha=.05$). Maximum density of white bass sampled was 283.3 larvae per 100 m³ on June 4 at Station MB1/1.

Yellow Perch

With a basin-wide mean density of 21.31 larvae per 100 m³, yellow perch larvae were the most abundant commercial or sportfish larvae captured in this study. Yellow perch larvae were first captured on April 20 and were collected during every sampling effort thereafter. Samples collected indicated peak larval yellow perch densities of 87 per 100 m³ occurred on May 2 (Figure 19).

No significant differences could be detected between larvae densities in Maumee Bay or along the Ohio and Michigan shoreline (Kruskal Wallis $\alpha=.05$). Friedman's Rank Sum Test could not detect significant differences between onshore and offshore densities of either pro-larvae or total number of perch larvae (i.e., pro- and post-larvae) but did indicate that larvae (combined pro- and post-larvae) densities were highest along the M2 and OH3 transects and lowest along the M5 and M3 transects (Figure 20). Pro-larvae densities were highest along transects M2 and M1 and lowest along transects A2, M3 and M5 (Figure 21). Maximum density of perch larvae (combined pro-and post-larvae) sampled was 665 larvae per 100 m³, 380 of which were pro-larvae, at Station M2/1 on May 1.

Walleye

With a mean basin-wide density of 0.99 larvae per 100 m³, walleye were the ninth most abundant larval species captured. Larval walleye were first collected on April 20 and were captured during the next three cruises. No walleye were found in samples collected after June 4. Samples collected indicated larval walleye densities were highest on May 1 with an average basin density of 4.6 larvae per 100 m³ (Figure 22).

Statistical differences were detected, indicating walleye larvae densities were greater along the Ohio shoreline than in Maumee Bay or along

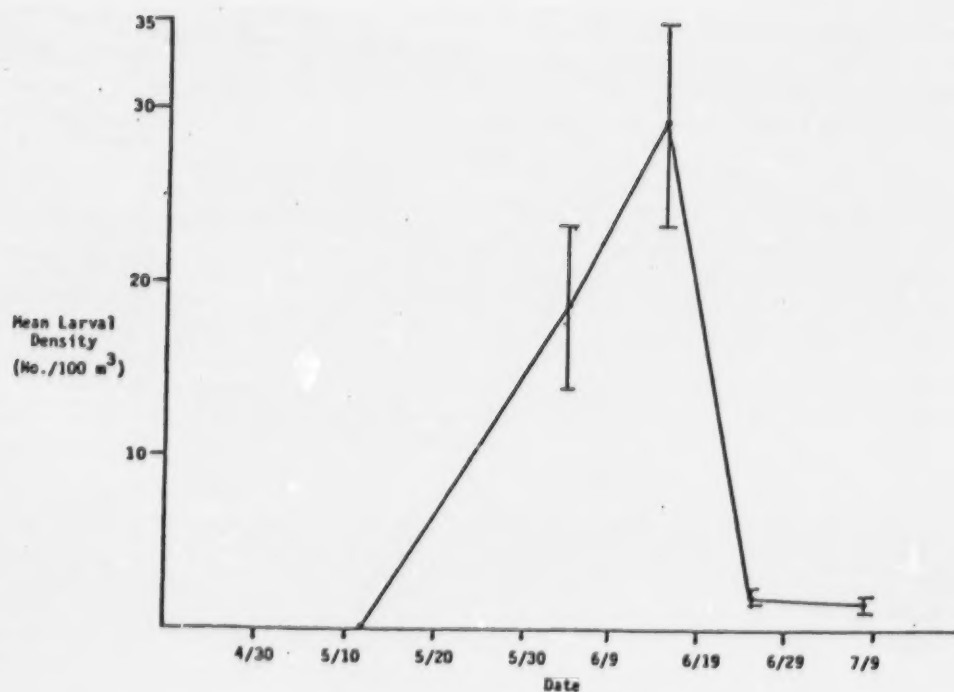


Figure 17. Mean Density of White Bass Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

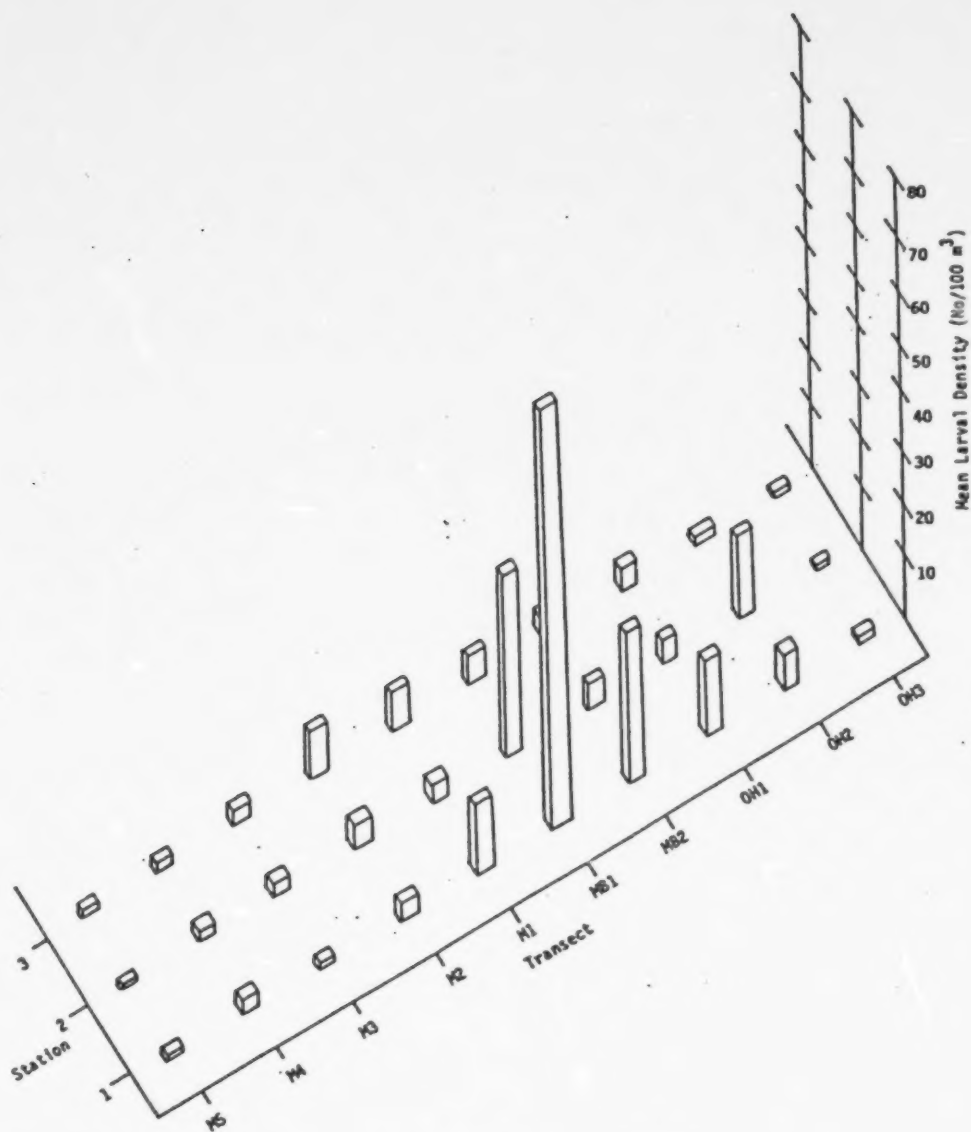


Figure 18. Western Basin - 1977.
Mean Density of White Bass Larvae at Each
Station.

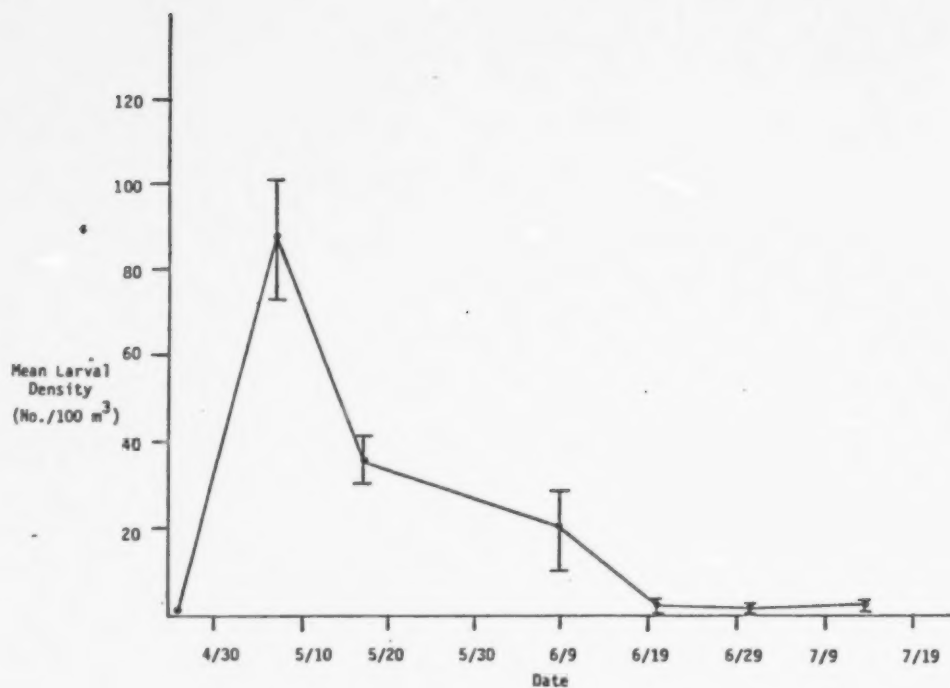


Figure 19. Mean Density of Yellow Perch Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

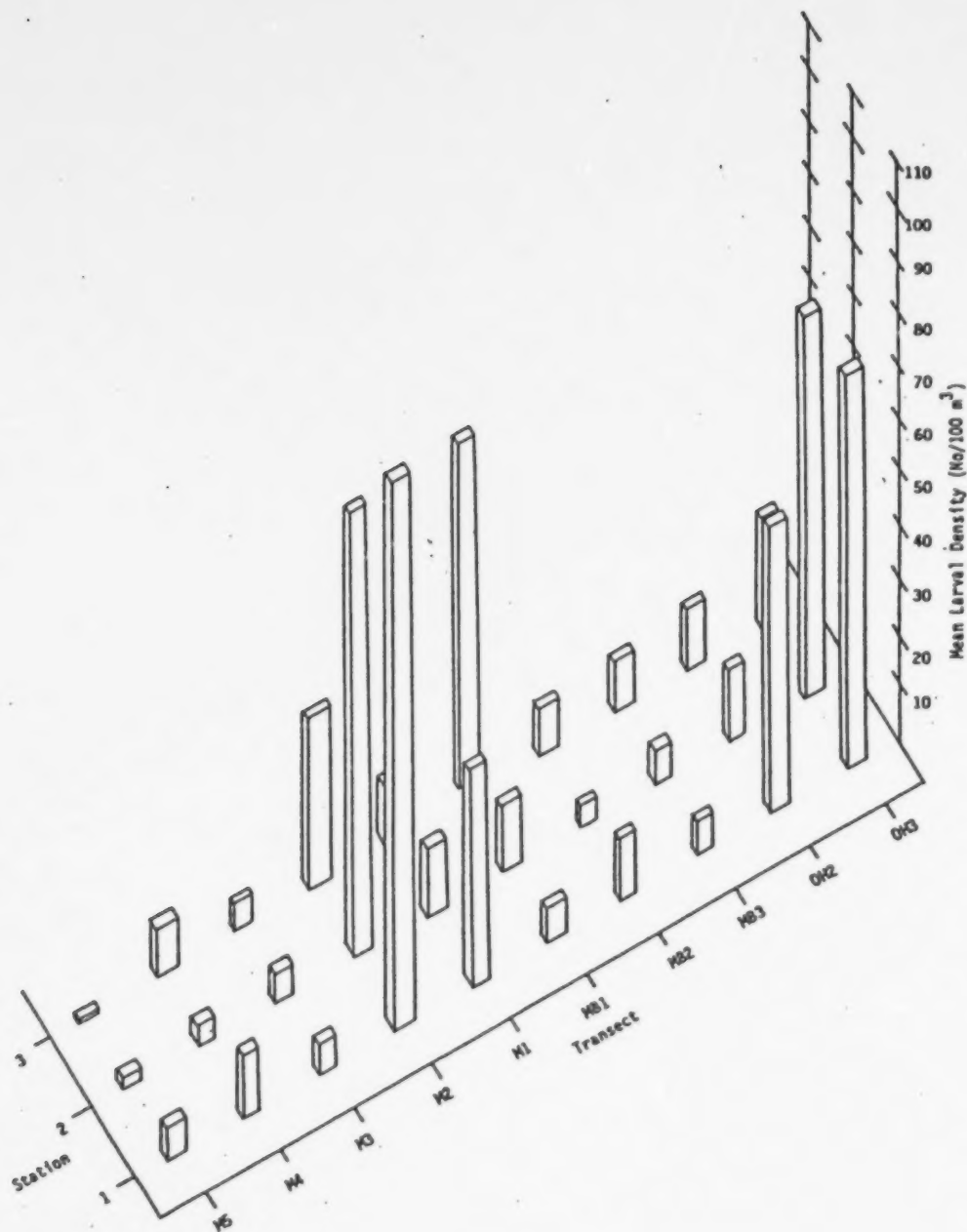


Figure 20. Western Basin - 1977.
Mean Density of Yellow Perch Larvae at Each
Station.

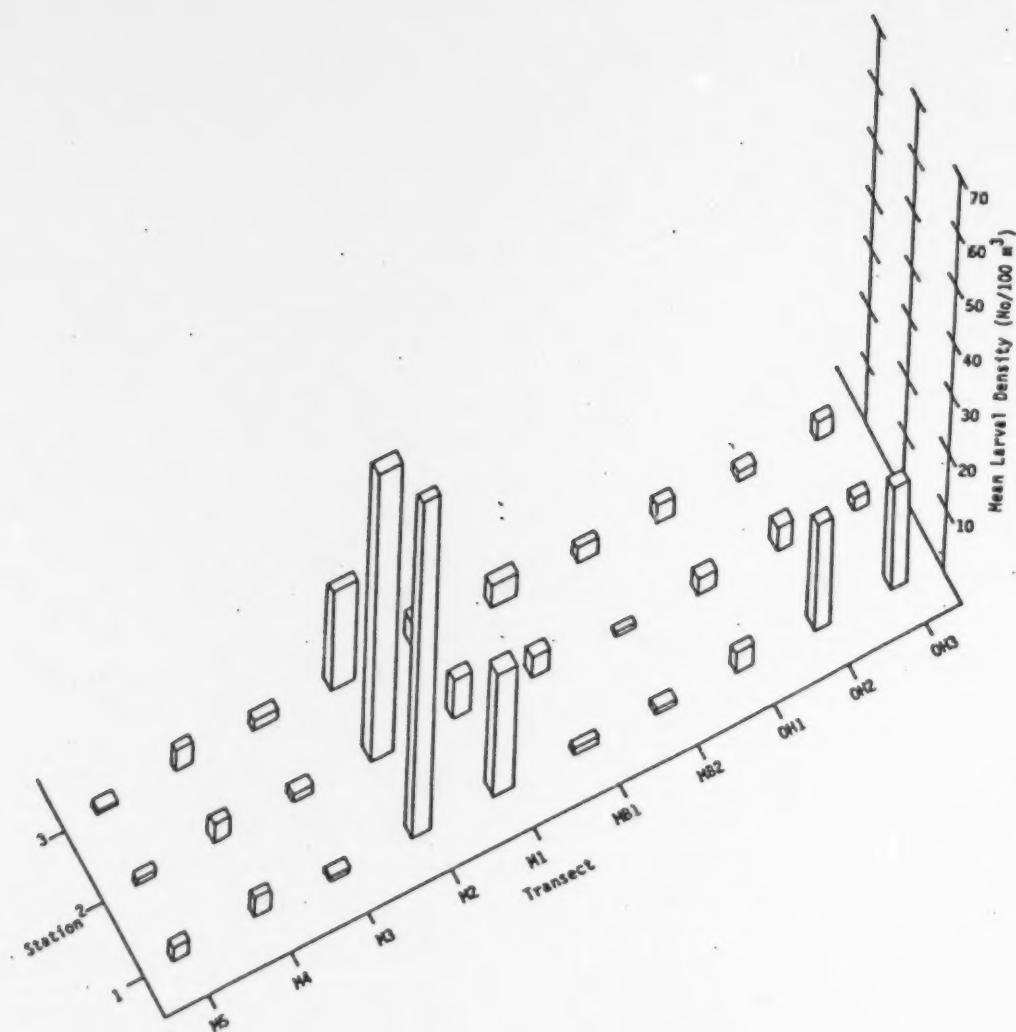


Figure 21. Western Basin - 1977.
Mean Density of Yellow Perch Pro-Larvae at
Each Station.

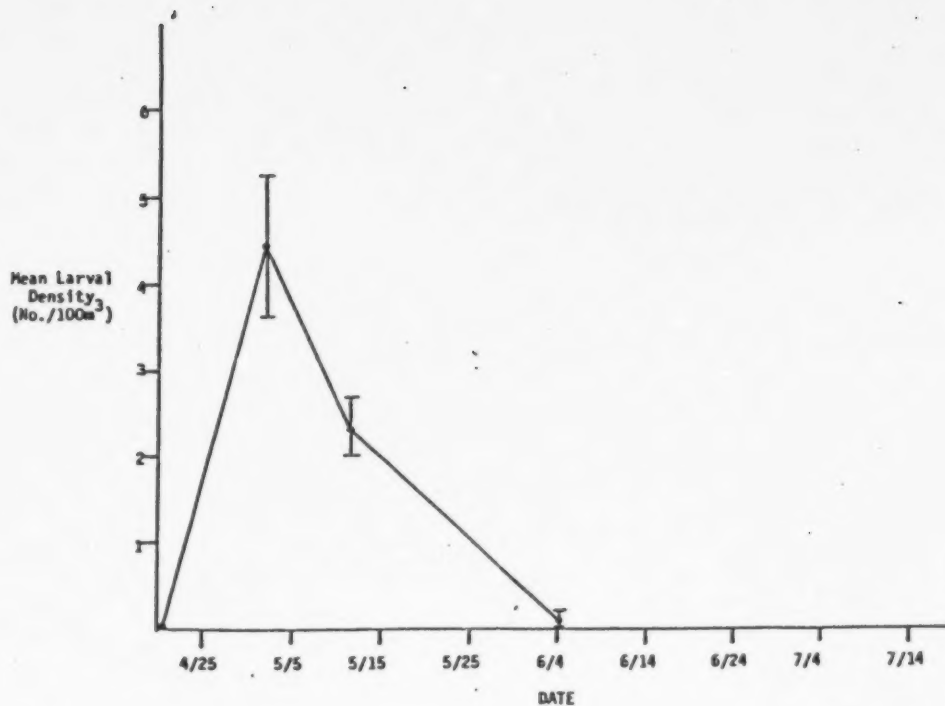


Figure 22. Mean Density of Walleye Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

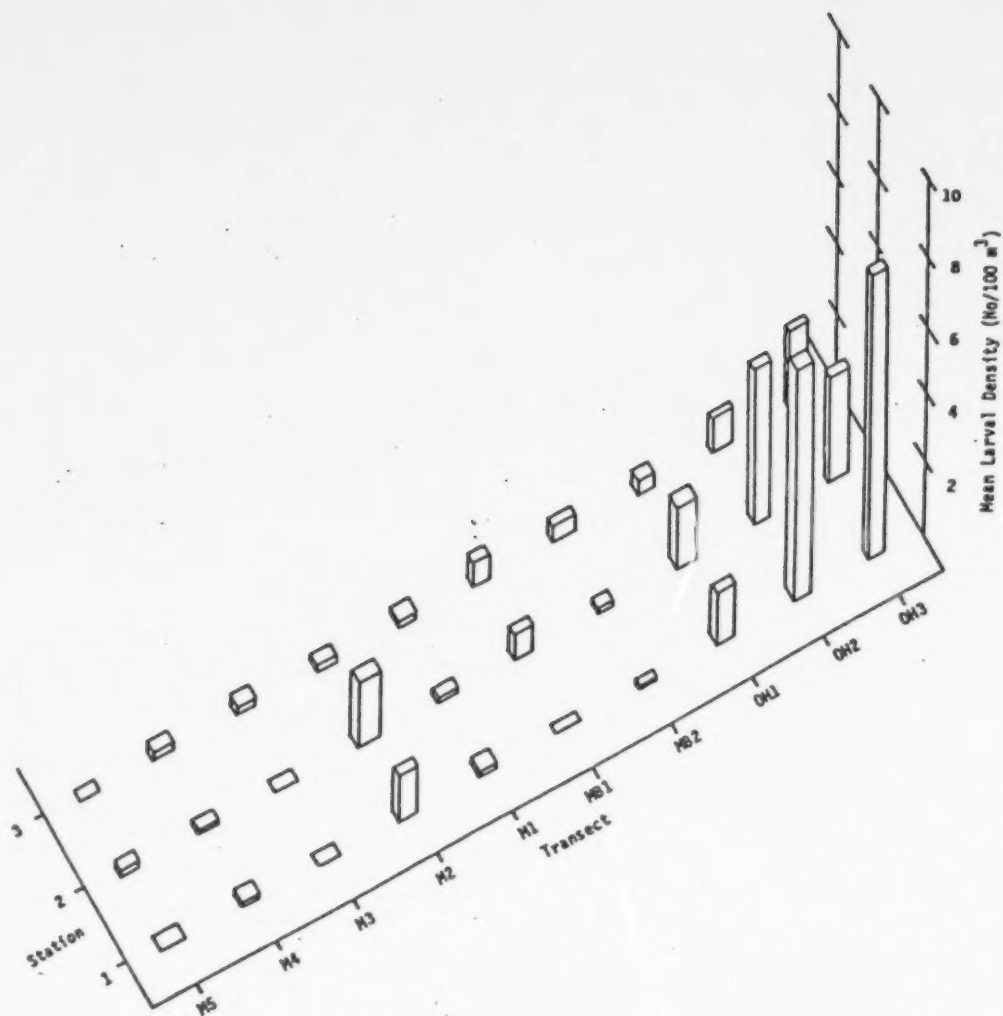


Figure 23. Western Basin - 1977.
Mean Density of Walleye Larvae at Each Station.

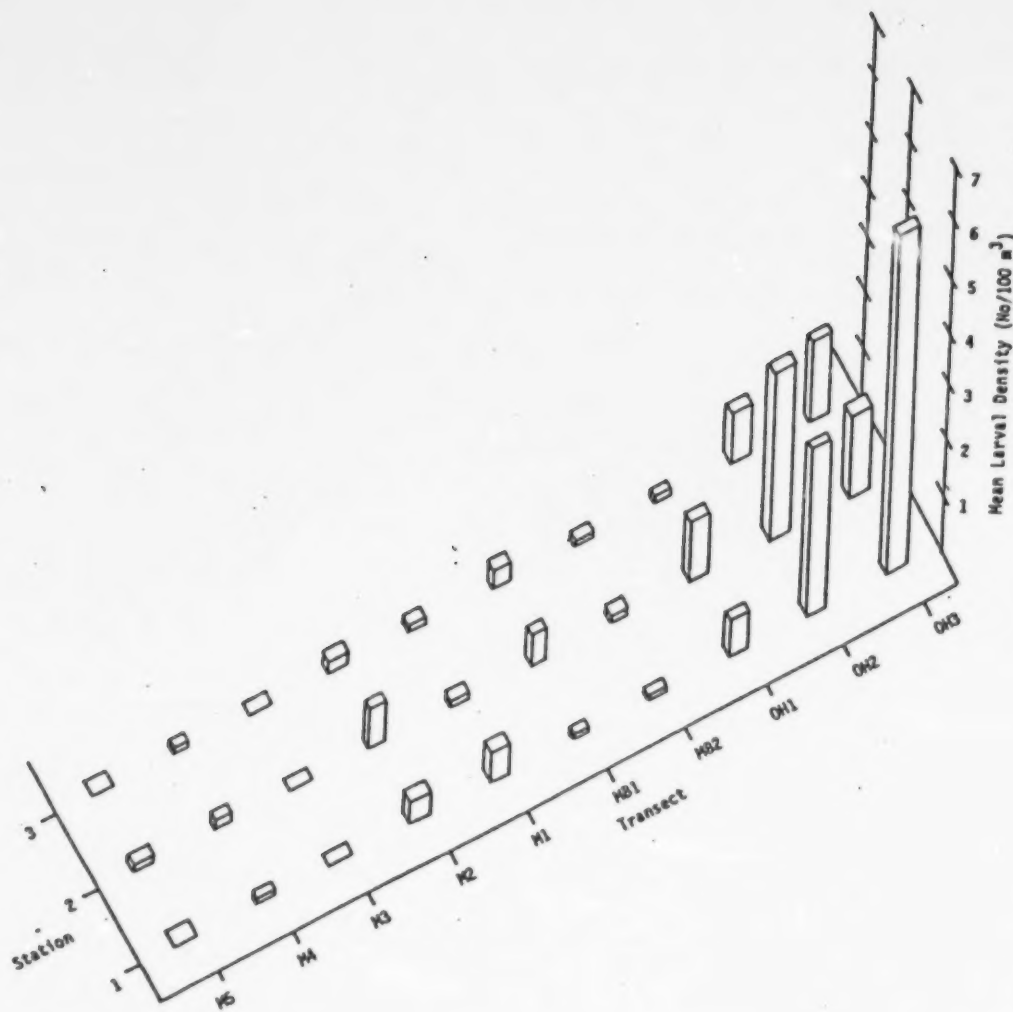


Figure 24. Western Basin - 1977.
Mean Density of Walleye Pro-Larvae at Each Station.

the Michigan shoreline for both larvae (pro- and post-larvae) and pro-larvae (Kruskal Wallis $\alpha=.05$). No statistical differences between onshore and offshore densities were detectable. Friedman's Rank Sum test ($\alpha=.05$, $df=9$) indicated that highest larvae and pro-larvae densities were found along transects OH3 and OH2 and lowest densities were along transects M3 and M5. Maximum densities of both pro-larvae (31 per 100 m³) and larval walleye (38 per 100 m³) were found at Station OH3/1. Figure 23 represents spatial distributions of larval walleye and Figure 24 represents spatial distributions of pro-larval walleye in the Western Basin in 1977.

Log Perch

With a basin-wide mean density of 1.43 larvae per 100 m³, log perch were the seventh most abundant larval species captured in the Western Basin in 1977. Log perch larvae were first collected on April 30 and were collected during every sampling effort thereafter. Samples collected indicated average larval densities in the basin reached a maximum of 4.76 larvae per 100 m³ on June 3 (Figure 25).

No statistical differences in density of logperch larvae were detectable between the three physiographic areas, onshore/offshore or between transects. Larval log perch densities were highest along transect M4 (40.8% of the total catch) and M5 (12% of the total catch) with a maximum density of 25.1 larvae per 100 m³ sampled on June 15. Figure 26 represents spatial distributions of larval log perch in the Western Basin in 1977.

Freshwater Drum

With a basin-wide mean density of 1.76 larvae per 100 m³, freshwater drum were the fifth most abundant species collected in the Western Basin in 1977. Drum larvae were first collected on June 3, with an average basin density of 3.2 larvae per 100 m³; by June 10 the average basin density had dropped to 1.08 larvae per 100 m³. Larval drum densities rose again reaching a maximum density of 5.6 larvae per 100 m³ on July 7 (Figure 27).

Statistical differences in density of larvae were detected for the three physiographic areas (Kruskal Wallis $\alpha=.05$) with highest densities found in Maumee Bay and lowest densities found along the Michigan shoreline. Friedman's Rank Sum test ($\alpha=.01$) detected significant differences between highest densities of larval fishes found along transects MB2 and OH2 and lowest densities along transects M3 and M1. No statistical differences were detectable between onshore and offshore densities (Figure 28). Maximum density of drum sampled was 78.5 larvae per 100 m³ at Station MB1/1 on July 7.

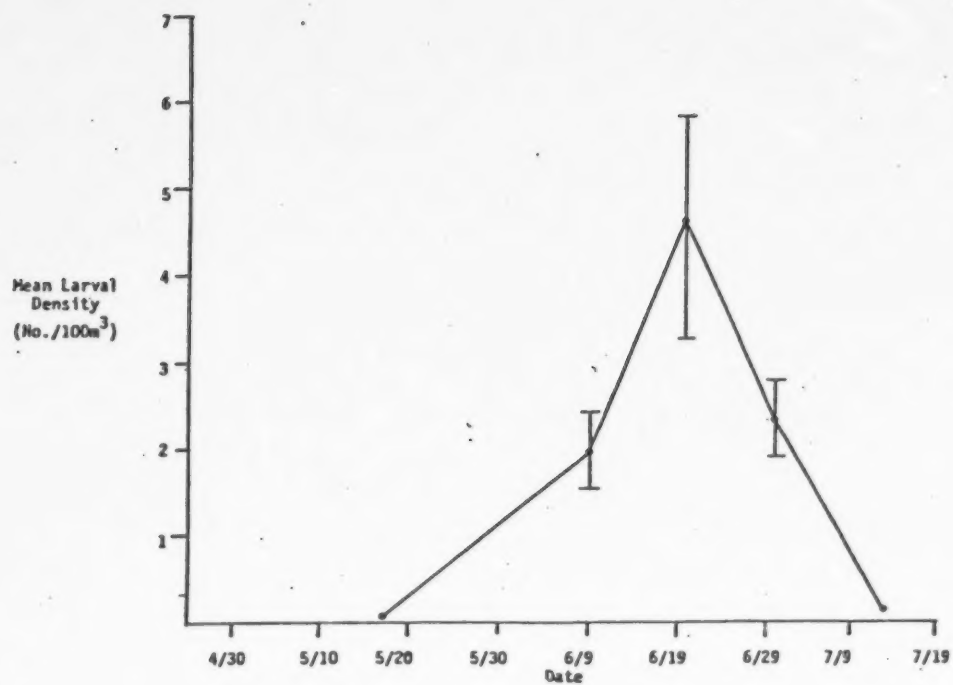


Figure 25. Mean Density of Log Perch Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

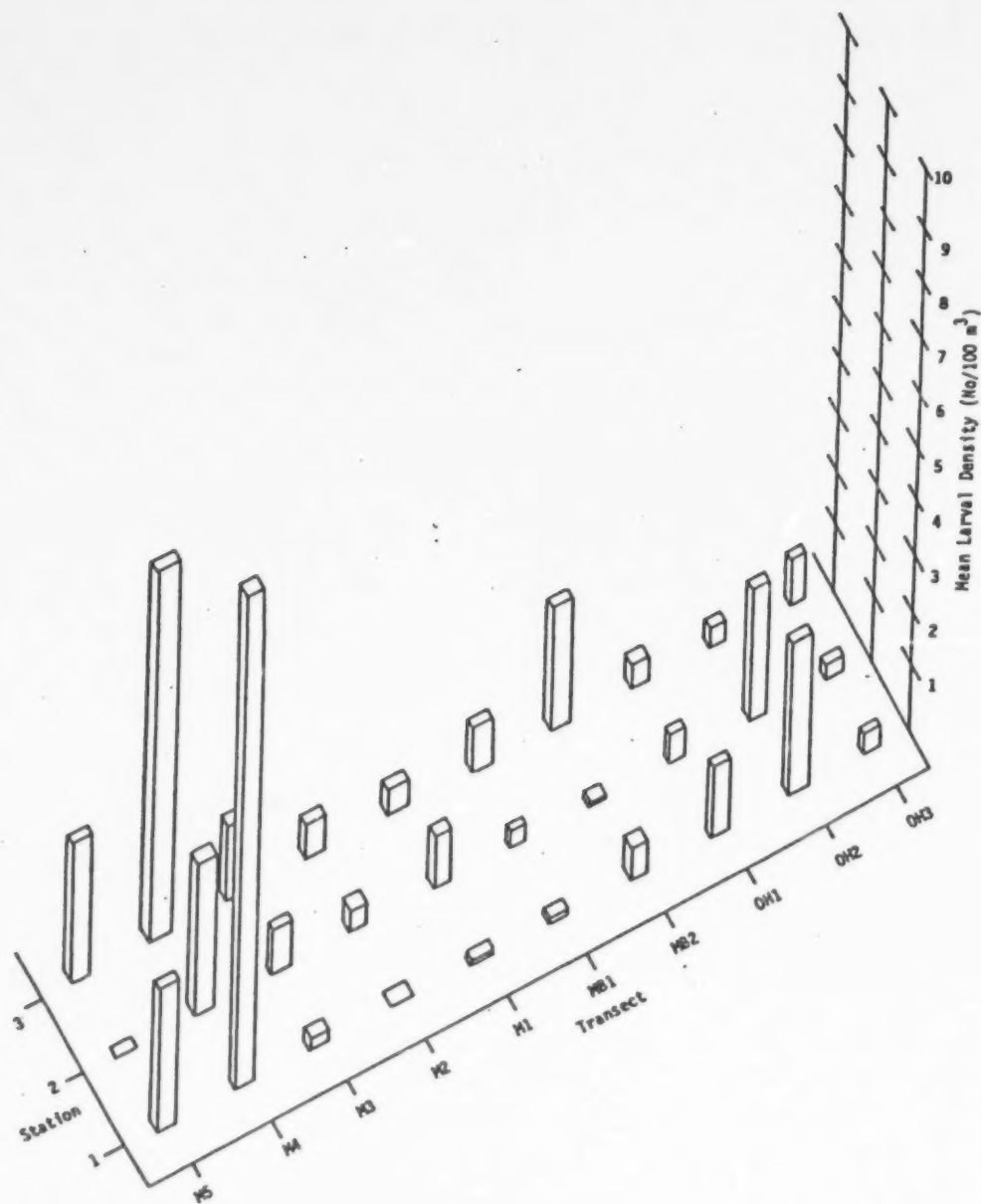


Figure 26. Western Basin - 1977.
Mean Density of Log Perch Larvae at Each
Station.

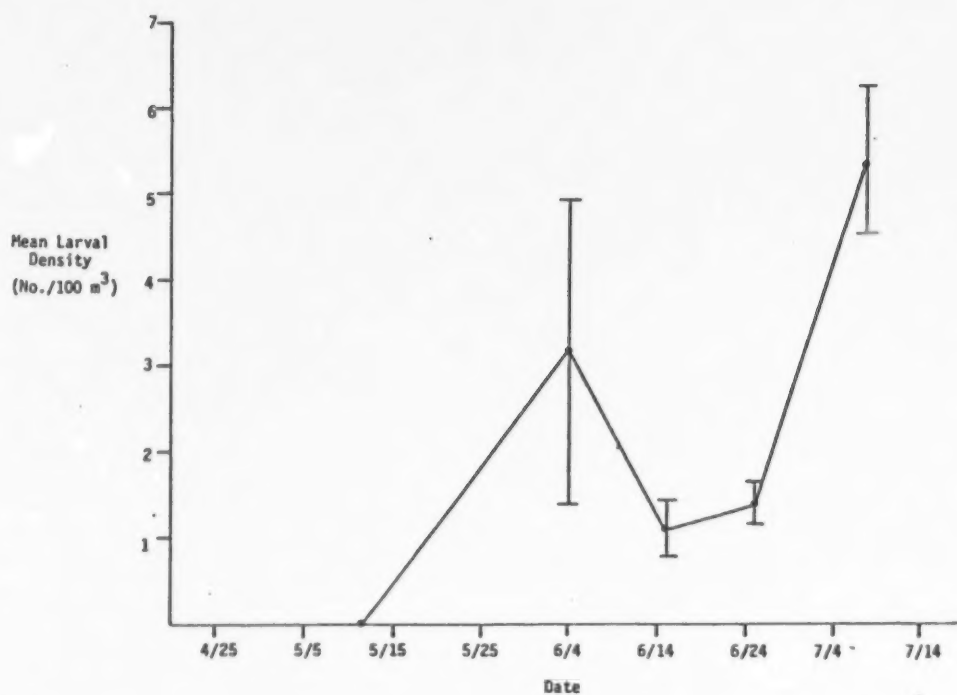


Figure 27. Mean Density of Freshwater Drum Larvae in the Western Basin During 1977. Distance between bars represents one standard error of the mean.

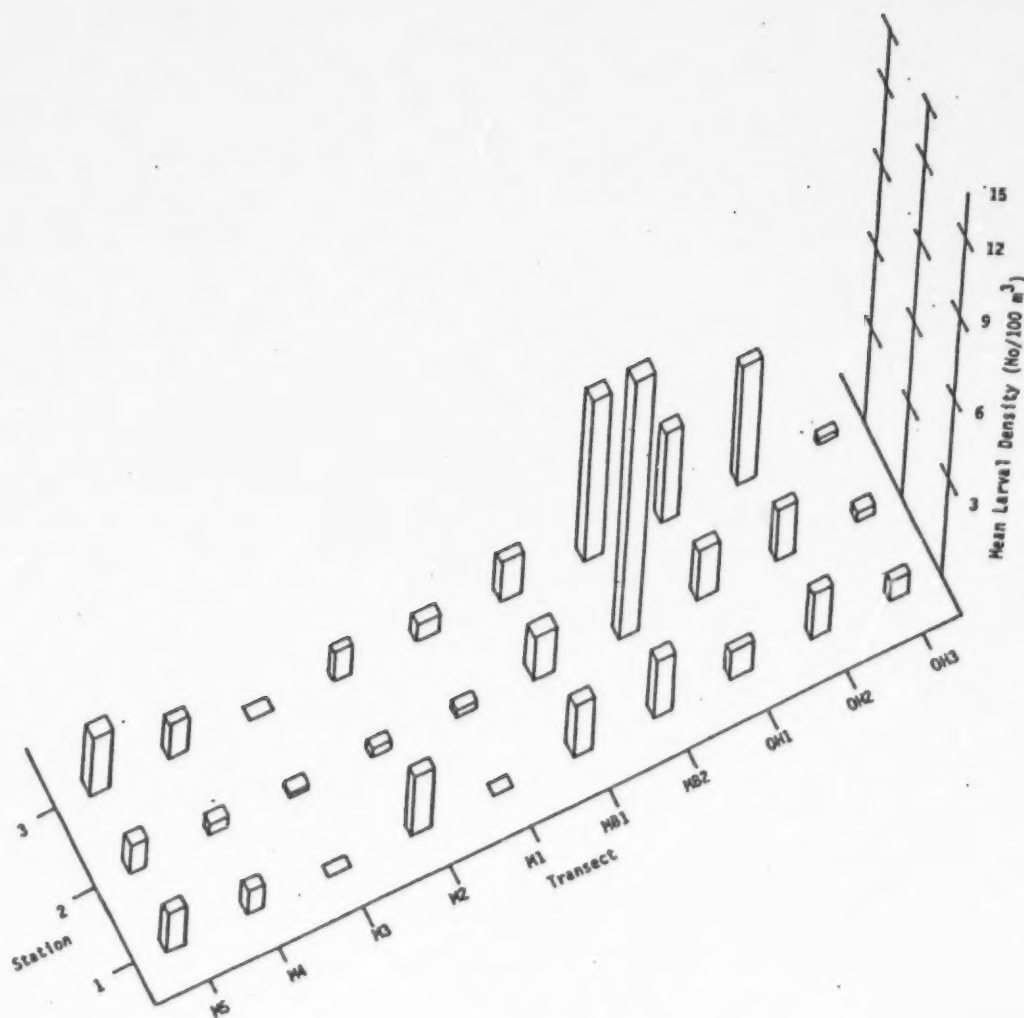


Figure 28. Western Basin - 1977.
Mean Density of Freshwater Drum Larvae at Each Station.

Central Basin

An intensive survey of the nearshore zone of the Central Basin in 1978 resulted in the collection of 28 taxa of larval fishes. Twenty-two species were identified representing 14 families and comprising 98.89% of the total catch; 1.03% were identified to genus or family level with only 0.08% remaining unidentified.

Nine species, emerald shiner, gizzard shad, spottail shiner, freshwater drum, rainbow smelt, carp, yellow perch, trout perch, and log perch were collected in numbers great enough (i.e., average basin-wide density $.10/100\text{ m}^3$) and occurred in samples often enough to be considered abundant. Johnny darter and mottled sculpin had average basin densities $.10$ per 100 m^3 , $.84$ and $.50$ larvae per 100 m^3 respectively, but since the capture of these larvae was limited to a few stations the author does not consider them to have been abundant in the Central Basin in 1978. Table 14 lists the average densities for the entire sampling period and percentages of the total catch represented by each taxon for the entire Central Basin.

Volume weighted estimates of total larval abundance are presented in Table 15. Volume weighted estimates differ from relative abundance of catch. Emerald shiners represent a large percentage of the total larval abundance, 54%, than relative abundance, 34%. Clupeid larvae and spottail shiner, although still ranked second and third each represent a smaller percentage of the total abundance than relative catch. Drum larvae, the fourth most abundant larvae captured, representing 4.21% of the total catch, is ranked eighth in relative abundance, comprising only 1.35% of total larval abundance.

A detailed description of the spatial and temporal distributions of the nine abundant larval species captured in the Central Basin follows. Station locations as referred to in the following can be found in Figure 29.

Clupeids (Gizzard Shad/Alewife)

With a mean basin density of 28.42 larvae per 100 m^3 , clupeid larvae were the second most abundant larval species captured. Larval clupeids were first collected on May 25 and were captured during every sampling effort thereafter. Samples collected indicated larval gizzard shad were most abundant on June 19 (Figure 30).

The highest densities of larval clupeids were collected west of Cleveland with over 60% of the catch occurring along transects 3 and 4 (Figure 31). Friedman's Rank Sum Test ($\alpha=.05$, $df=9$) detected significant differences between transects 3 and 4 and transect 7, where the lowest densities were found, and ($\alpha=.05$, $df=2$) identified the mid-depth zone as having the lowest densities of larval gizzard shad and depth zone 1 as having the highest densities. Maximum density of gizzard shad sampled was 437 larvae per 100 m^3 at Station 3/1 on July 17.

Rainow Smelt

With an average density of 3.40 larvae per 100 m³ smelt were the fifth most abundant larvae captured in the Central Basin in 1978. Smelt larvae were first captured on May 20 and were captured during every sampling effort thereafter. Samples collected indicated smelt densities reached their maximum on July 5 with an average basin density of 14.6 larvae per 100 m³ (Figure 32).

Although 72% of smelt larvae were captured offshore, Friedman's Rank Sum Test ($\alpha=.05$, $df=2$) was unable to detect statistical differences between onshore and offshore densities of smelt larvae. The majority of smelt larvae were captured west of Cleveland with transects 1-4 contributing to 68.25% of the smelt catch (Figure 33). No statistical differences were detectable for differences in densities of larvae between transects. Maximum density of smelt sampled was 100.1 larvae per 100 m³ at Station 3/2 on July 5.

Carp/Goldfish and their Hybrids

With a mean basin density of 2.58 larvae per 100 m³ carp larvae were the sixth most abundant larval fish captured. Carp larvae were first captured on May 24 and were found in samples collected during each sampling effort thereafter. Samples collected indicated carp densities were highest on July 6 with a mean basin density of 11.3 larvae per 100 m³ (Figure 34).

Friedman's Rank Sum Test ($\alpha=.01$, $df=2$) detected statistical differences between onshore and offshore densities. 89% of the total number of carp larvae captured occurred in depth zone 1 (Figure 35). Although 62% of the carp larvae were captured along transect 9, no statistical differences in densities could be detected between transects. Maximum density of carp larvae sampled was 269 larvae per 100 m³ at Station 9/1 on July 8.

Emerald Shiner

Emerald shiner larvae were the most abundant larval fish species collected in the Central Basin in 1978. Emerald shiner larvae were first captured on June 16 and were captured during every sampling effort thereafter. Emerald shiner larvae were most abundant in samples collected on July 21, with a calculated basin-wide average of 195 larvae per 100 m³ (Figure 36).

Emerald shiner larvae were most abundant along the shoreline east of Cleveland with 76.5% of the total emerald catch made between transects 1 and 4. Lowest emerald shiner densities were found in the Cleveland area, transects 5 and 6 (Figure 37). Friedman's Rank Sum Test ($\alpha=.05$, $df=9$) detected significant differences between areas of highest densities along transect 3 and areas of lowest larval density along transects 5 and 6. No significant differences were detected between onshore and offshore densities. Maximum density of emerald shiner sampled was 2329 per 100 m³ at Station 3/3 on July 21.

TABLE 14. RELATIVE ABUNDANCE OF LARVAL FISHES CAPTURED ALONG THE OHIO SHORELINE OF THE CENTRAL BASIN IN 1978

SPECIES	AVERAGE DENSITY	PERCENTAGE OF TOTAL CATCH
Emerald Shiner	32.30	34.28
Gizzard Shad/Alewife	28.42	30.53
Spottail Shiner	16.37	17.58
Freshwater Drum	3.92	4.21
Rainbow Smelt	3.40	3.66
Carp	2.85	3.06
Yellow Perch	1.25	1.34
Trout Perch	1.00	1.01
Johnny Darter	0.80	0.84
Log Perch	0.74	0.79
Mottled Sculpin	0.47	0.50
Cyprinidae	0.46	0.48
<u>Notropis</u> sp.	0.25	0.26
Percidae	0.20	0.21
Unidentified Larvae	0.07	0.08
<u>Lepomis</u> sp.	0.07	0.06
Striped Shiner	0.06	0.06
White Sucker	0.05	0.04
Walleye	0.04	0.04
White Bass	0.03	0.03
Rock Bass	0.02	0.03
Burbot	0.02	0.03
Golden Shiner	0.02	0.02
<u>Pomoxis</u> sp.	0.01	0.02
Sauger	0.01	0.02
Quillback Carpsucker	0.01	< 0.01
Black Crappie	0.01	< 0.01
Smallmouth Bass	0.01	< 0.01

¹Average density found by dividing the sum of the calculated densities by the number of samples collected during the period of larval occurrence.

Species ranked in descending order of average density.

TABLE 15. VOLUME WEIGHTED ESTIMATES OF TOTAL PRODUCTION OF LARVAL FISHES IN THE NEARSHORE ZONE OF THE CENTRAL BASIN IN 1978

SPECIES	VOLUME WEIGHTED TOTAL	% OF TOTAL ABUNDANCE ¹
Emerald Shiner	4.28×10^9	54.14
Gizzard Shad/Alewife	1.51×10^9	19.07
Spottail Shiner	8.32×10^8	10.53
Rainbow Smelt	4.28×10^8	5.42
Carp	1.26×10^8	1.59
Johnny Darter	1.12×10^8	1.40
Yellow Perch	1.09×10^8	1.38
Freshwater Drum	1.07×10^8	1.36
<u>Cyprinidae</u> spp.	1.04×10^7	1.23
Trout Perch	9.75×10^7	1.00
Mottled Sculpin	5.89×10^7	0.68
Log Perch	5.23×10^7	0.66
<u>Percidae</u> spp.	3.40×10^7	0.44
Black Crappie	2.16×10^7	0.27
<u>Pomoxis</u> spp.	1.43×10^6	0.18
Striped Shiner	7.65×10^6	0.10
Walleye	5.69×10^6	0.07
Burbot	2.58×10^6	0.03
White Bass	1.92×10^6	0.02
<u>Lepomis</u> spp.	1.89×10^6	0.02
White Sucker	1.65×10^6	0.02
Sauger	1.14×10^6	0.01
Quillback Carpsucker	5.55×10^5	<0.01
Golden Shiner	2.67×10^5	<0.01
Greenside Darter	2.59×10^5	<0.01
Total	7.90×10^{10}	

¹ Species ranked in descending order of abundance.



Figure 29. Sampling Stations in the Central Basin in 1978.

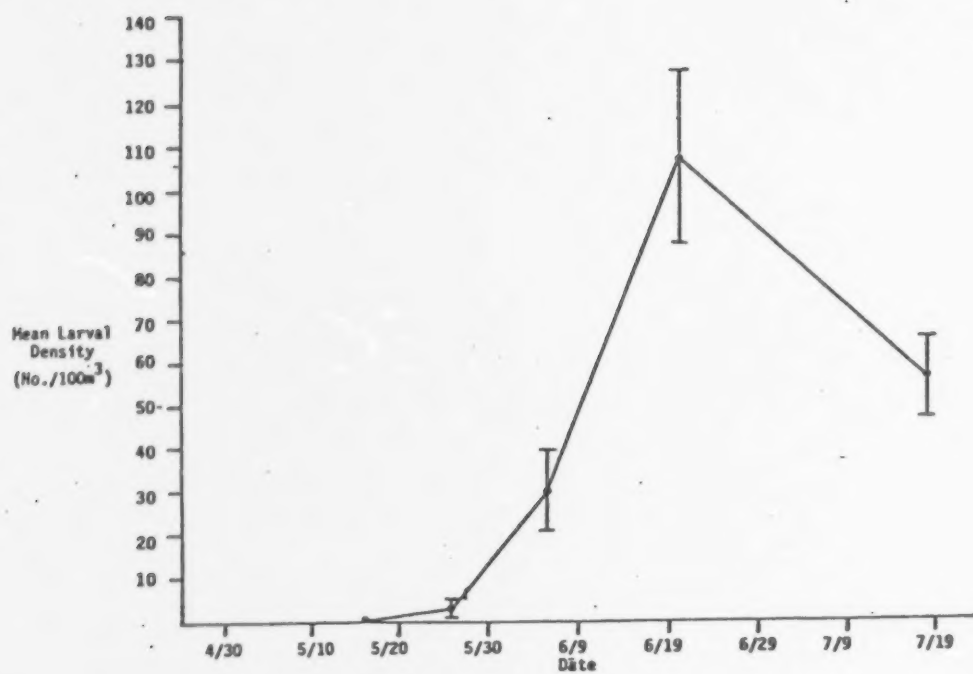


Figure 30. Mean Density of Clupeid Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

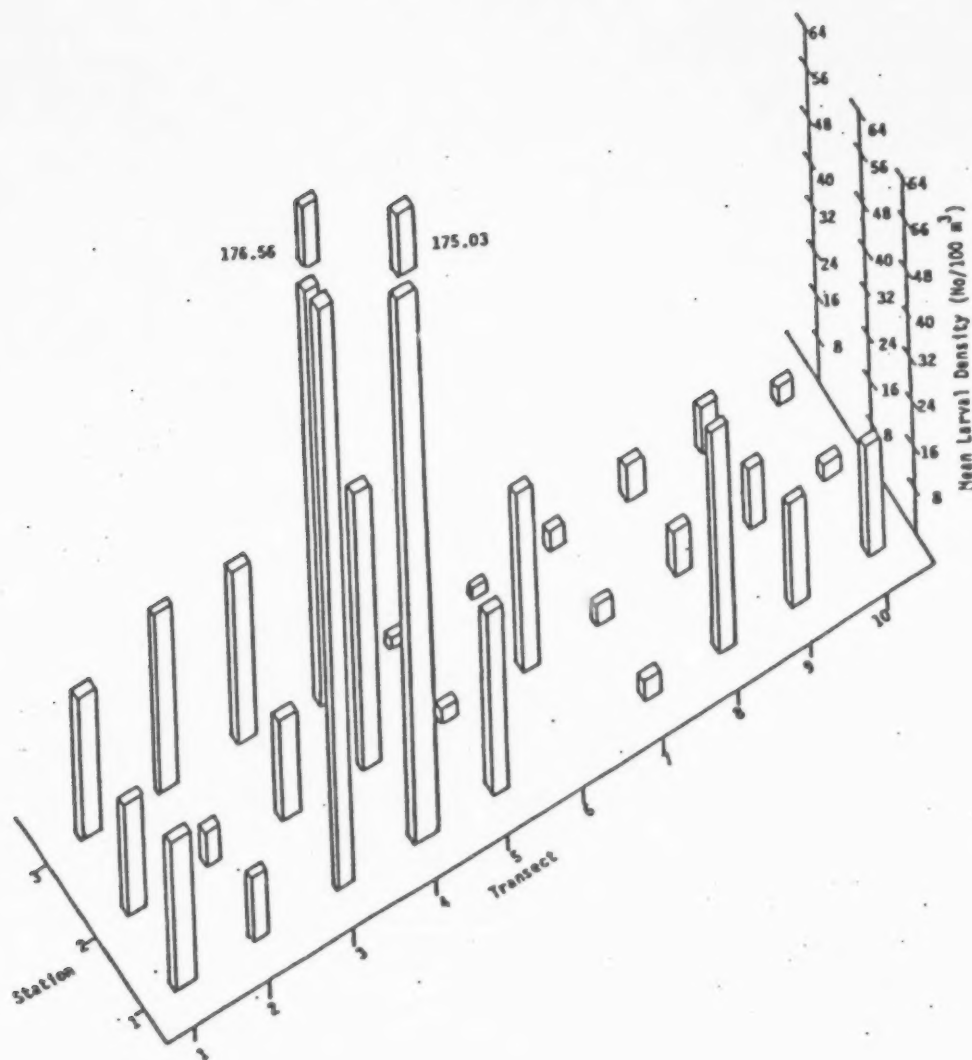


Figure 31. Central Basin - 1978.
Mean Density of Clupeid Larvae at Each Station.

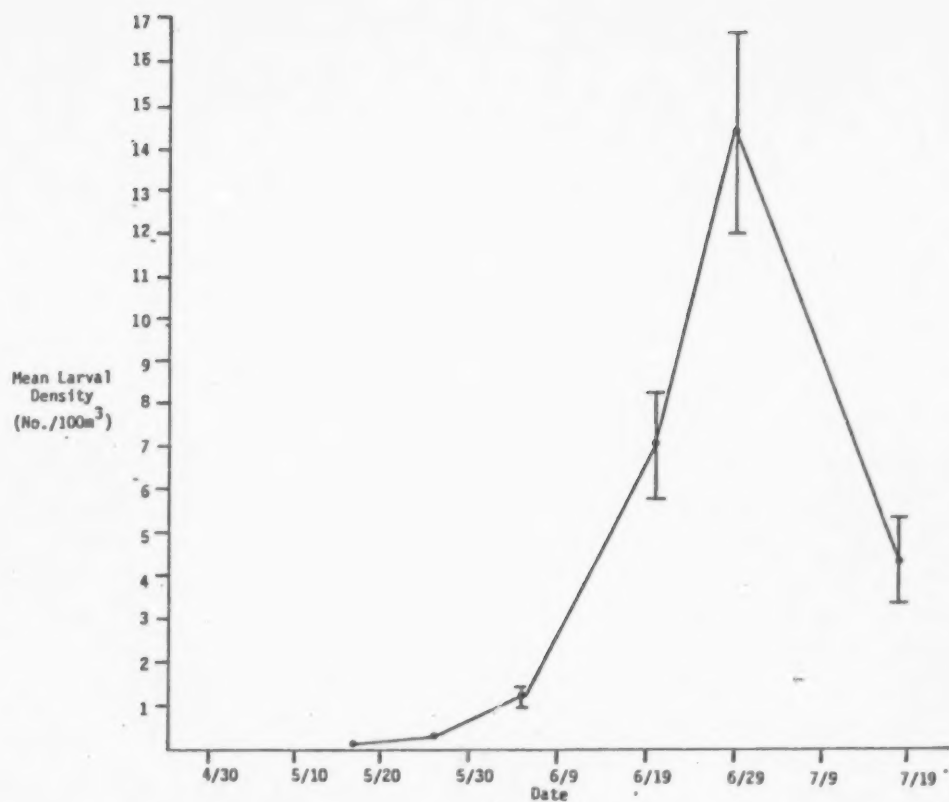


Figure 32. Mean Density of Smelt Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

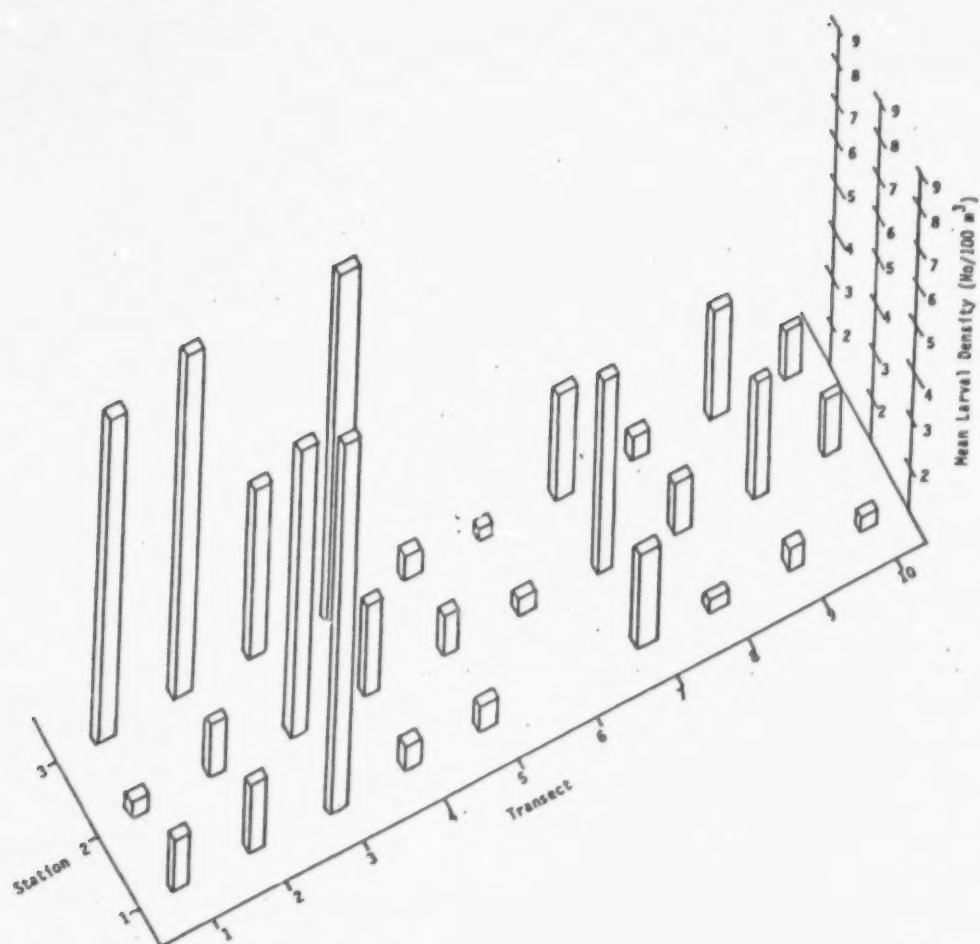


Figure 33. Central Basin - 1978.
Mean Density of Rainbow Smelt Larvae at Each
Station.

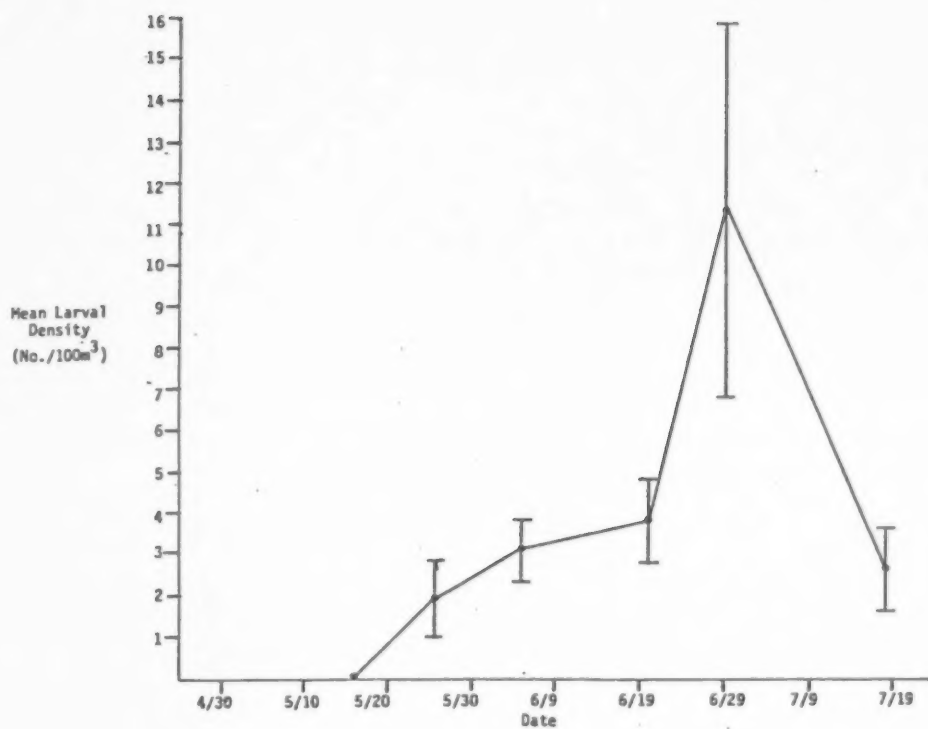


Figure 34. Mean Density of Carp Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

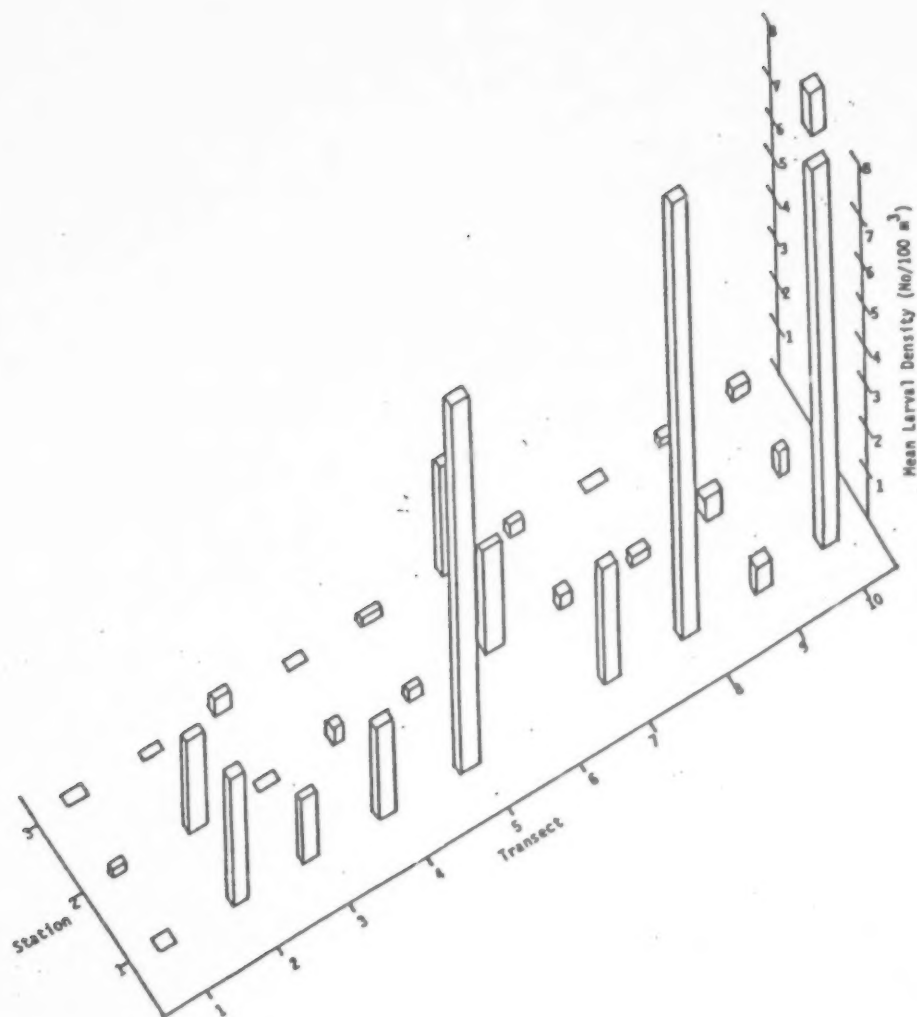


Figure 35. Central Basin - 1978.
Mean Density of Carp Larvae at Each Station.

Spottail Shiner

With a basin-wide average density of 16.37 larvae per 100 m³, spottail shiner larvae were the third most abundant species captured in the Central Basin in 1978. Spottails were first captured on July 16 and were captured during every sampling effort thereafter. Samples indicated maximum density of spottails occurred on June 27 with a basin-wide average density of 54 larvae per 100 m³ (Figure 38).

Friedman's Rank Sum Test ($\alpha=.01$, $df=2$) indicated significantly more larvae were captured at the nearshore stations than the midway or offshore stations. Ninety-four percent of the total spottail catch was made in depth zone 1. Significant differences were also detected between areas of highest, along transects 8, 9, and 10, and lowest larval densities along transects 2 and 6 ($\alpha=.05$, $df=9$) (Figure 39). Maximum larval density sampled was 1168 larvae per 100 m³ at Station 9/1 on July 21.

Trout Perch

With an average basin-wide density of 1.0 larvae per 100 m³, trout perch were the eighth most abundant larval species captured in the Central Basin in 1978. Larval trout perch were first captured on May 23 and were captured during every sampling effort thereafter. Samples collected indicate larval densities of trout perch were highest on June 11 with a basin-wide mean larval density of 11.75 larvae per 100 m³ (Figure 40).

Very few larval trout perch were captured west of Cleveland with 83.3% of the total trout perch catch coming from transects 8, 9, and 10 (Figure 41). Friedman's Rank Sum Test ($\alpha=.01$, $df=9$) indicated densities along transects 8, 9, 10 to be significantly greater than those along 1, 4, and 5. Seventy-four percent of the total trout perch were captured in the first depth zone. Friedman's test ($\alpha=.05$, $df=2$) indicated onshore densities were greater than offshore densities. Maximum density of trout perch sampled was 45.6 larvae per 100 m³ at Station 8/1 on May 23.

Yellow Perch

With an average basin-wide density of 1.25 larvae per 100 m³, yellow perch were the seventh most abundant species captured in the Central Basin in 1978. Yellow perch larvae were first captured on May 11 and were captured during every sampling effort thereafter. Samples collected indicated yellow perch larvae densities were highest at 6.2 larvae per 100 m³ on June 19 (Figure 42).

Eighty-seven percent of the total number of yellow perch larvae captured were pro-larvae. Friedman's Rank Sum Test ($\alpha=.01$, $df=2$) indicated significantly higher numbers of yellow perch larvae were captured in depth zone 1 than in depth zones 2 or 3 (77% of the total larvae catch was made in depth zone 1). Although transects 8, 9, and 10 accounted for 19, 20 and 29% of the total pro-larvae captured and 16, 20 and 23% of the total number of yellow perch larvae captured, no significant differences in larvae densities could be detected between transects (Friedman's Rank Sum, $\alpha=.05$, $df=9$). Figures 43 and 44 graphically demonstrate the spatial distributions of pro-larvae and larval yellow

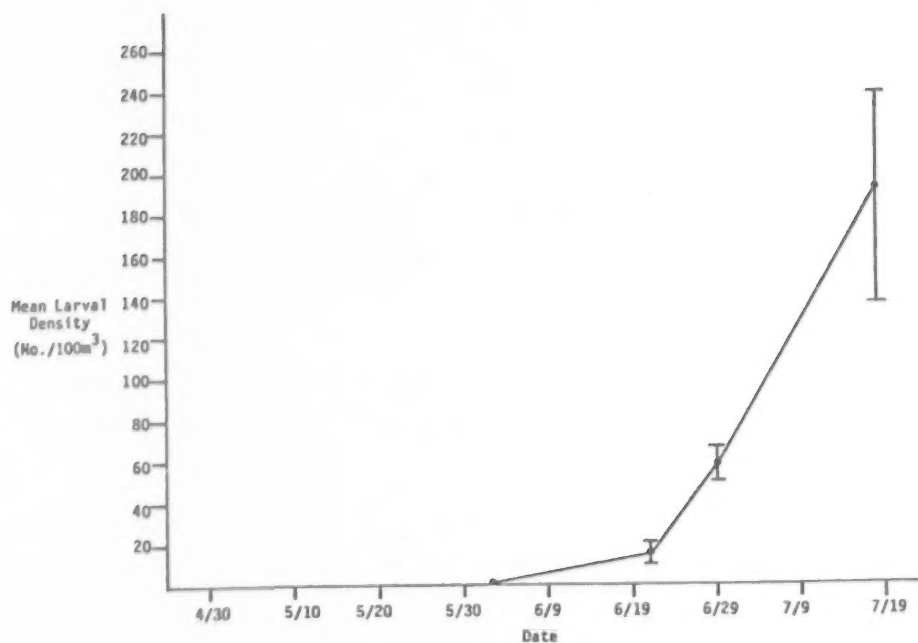


Figure 36. Mean Density of Emerald Shiner Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

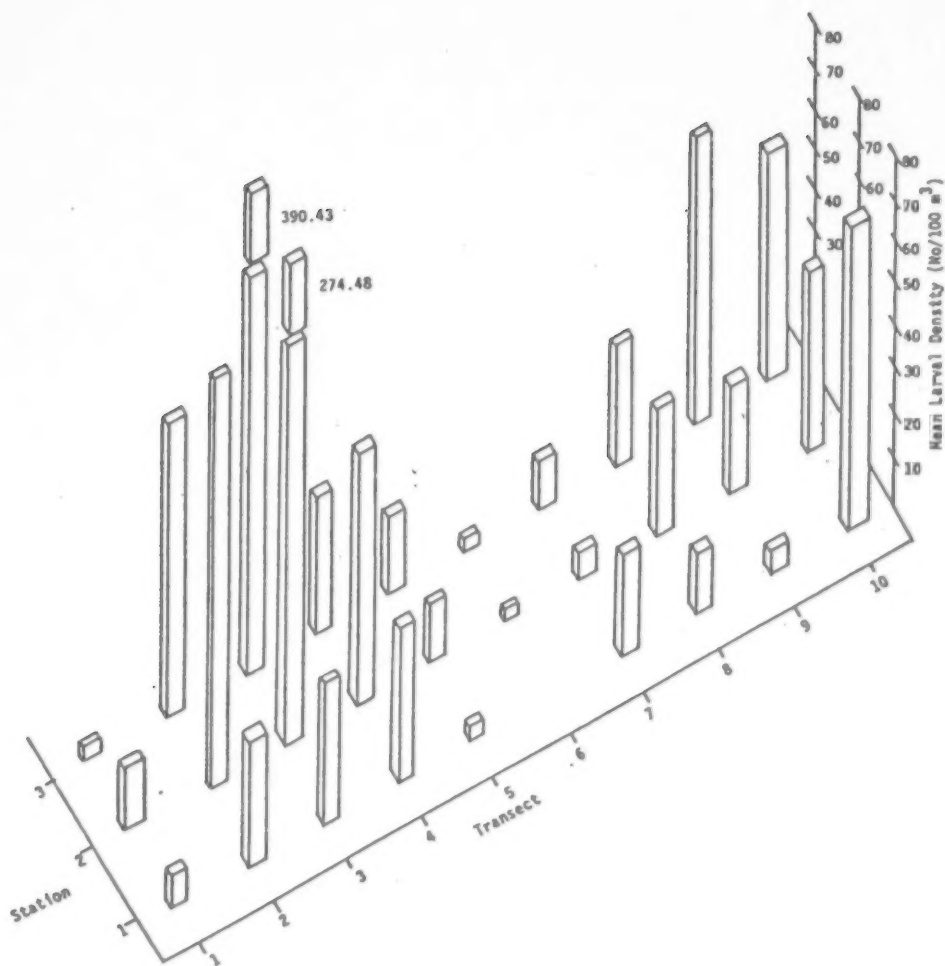


Figure 37. Central Basin - 1978.
Mean Density of Emerald Shiner Larvae at Each
Station.

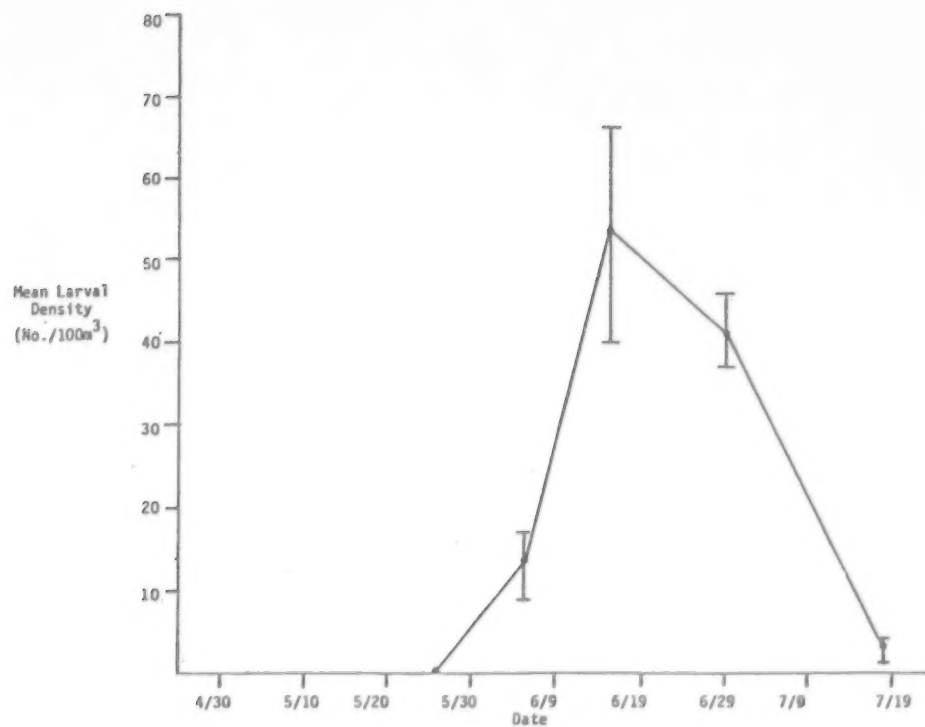


Figure 38. Mean Density of Spottail Shiner Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

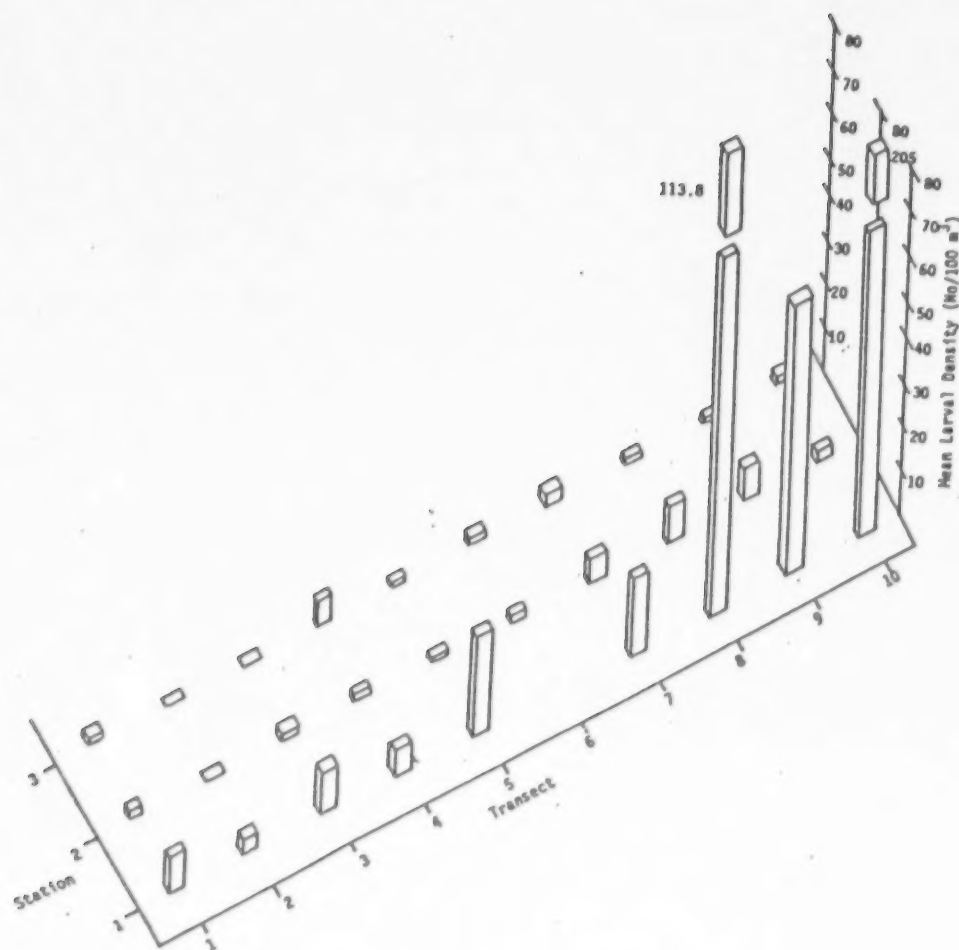


Figure 39. Central Basin - 1978.
Mean Density of Spottail Shiner Larvae at Each
Station.

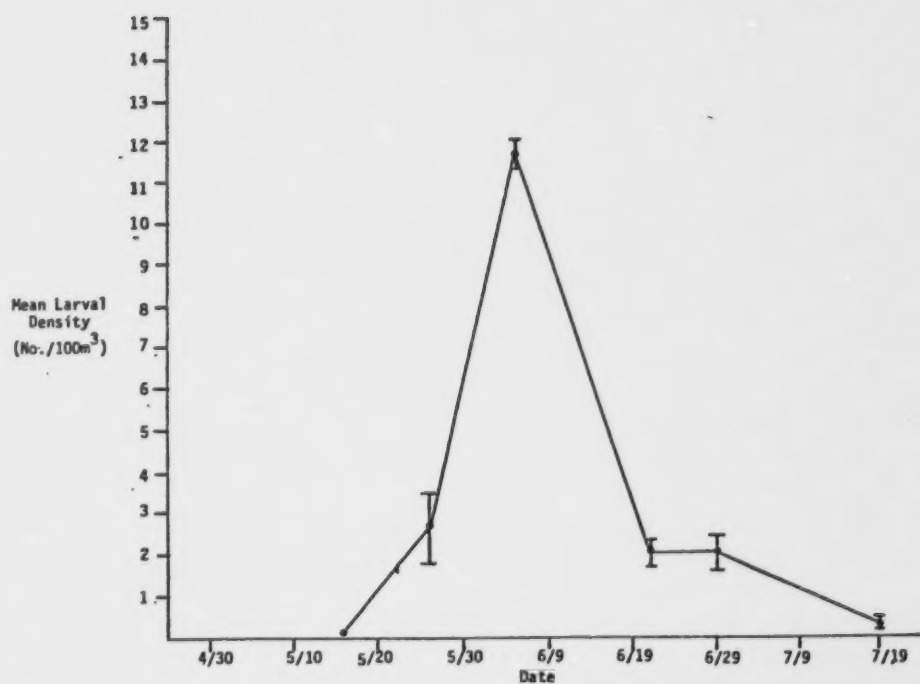


Figure 40. Mean Density of Trout Perch Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

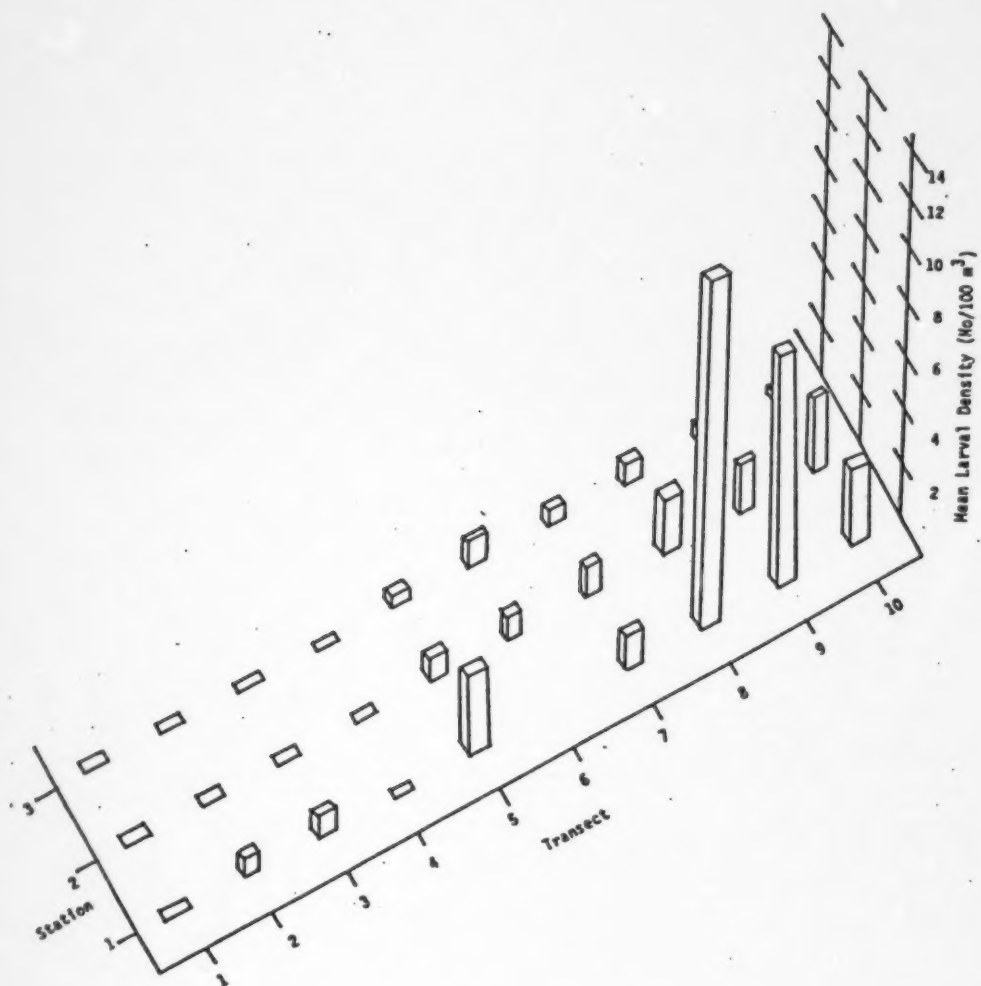


Figure 41. Central Basin - 1978.
Mean Density of Trout Perch Larvae at Each
Station.

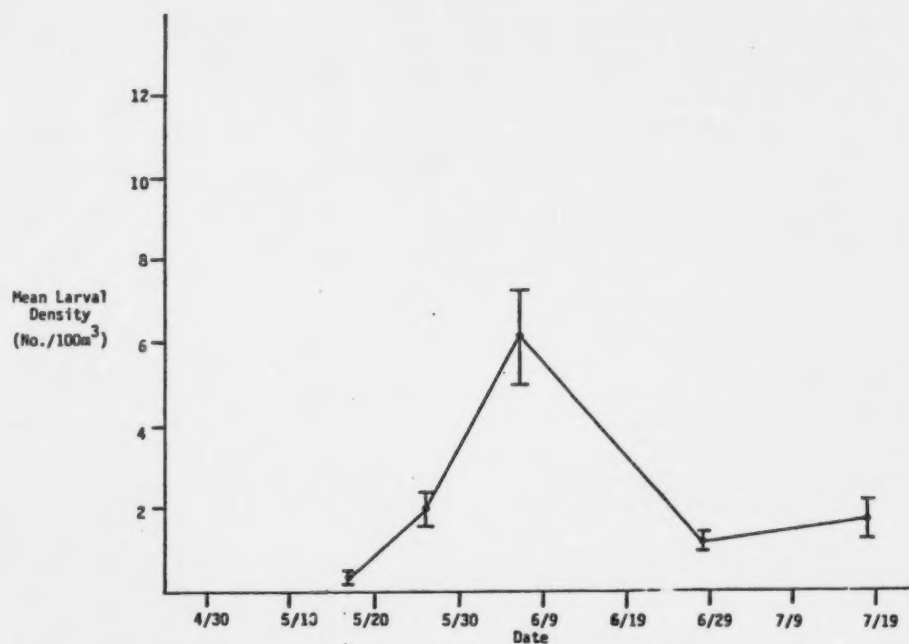


Figure 42. Mean Density of Yellow Perch Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

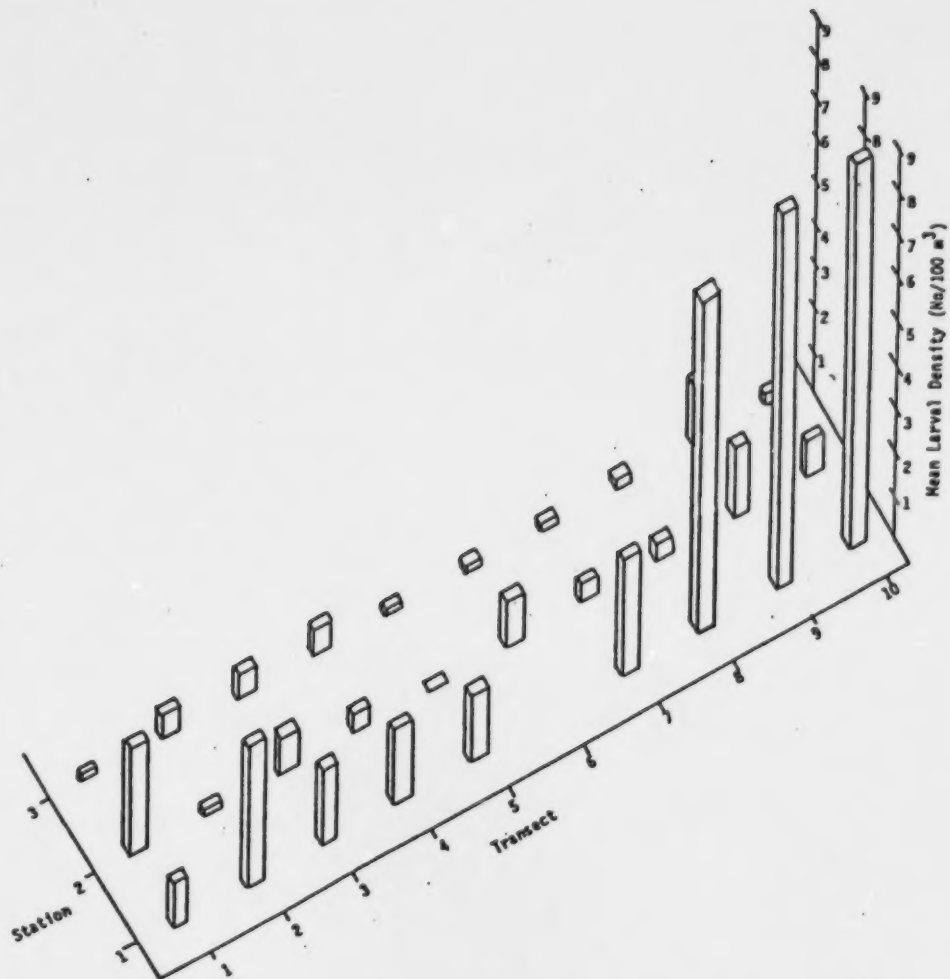


Figure 43. Central Basin - 1978.
Mean Density of Yellow Perch Larvae at Each
Station.

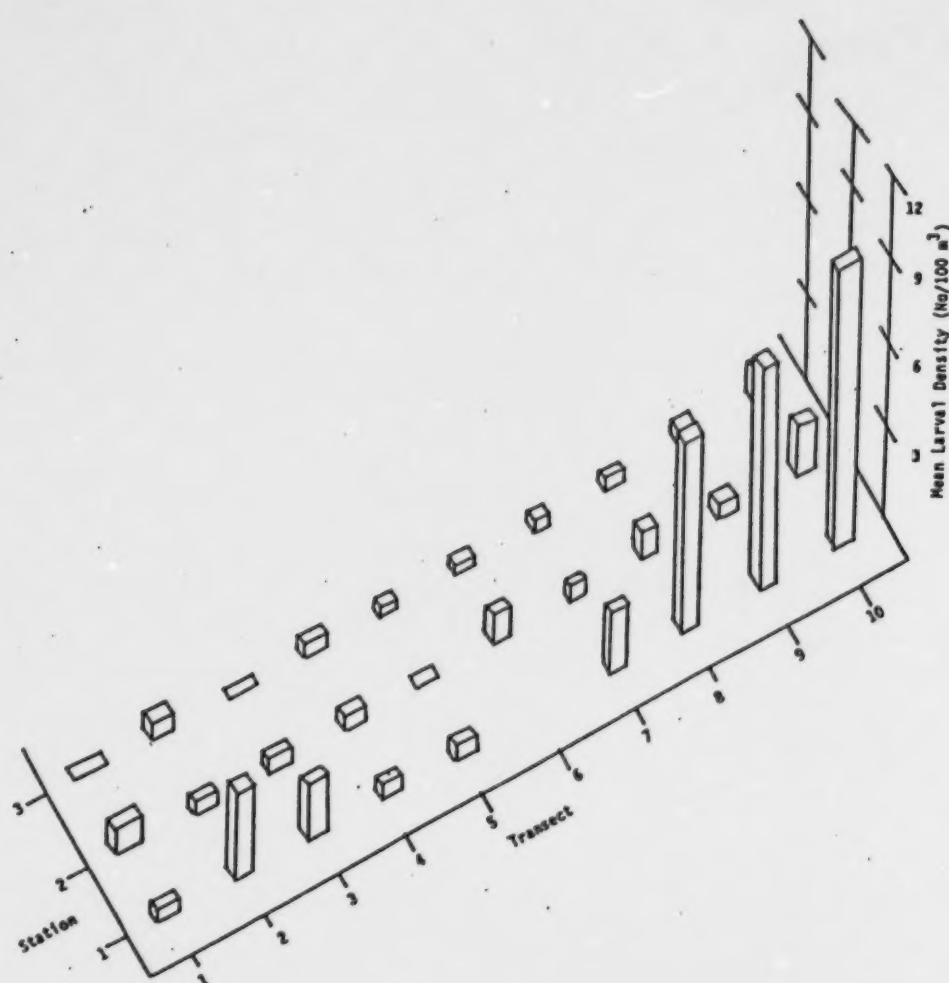


Figure 44. Central Basin - 1978.
Mean Density of Yellow Perch Pro-Larvae at Each Station.

the basin. The majority of white bass found in Maumee Bay were probably spawned over the sandy dredge spoil islands on both sides of the Toledo navigation channel or near the Ottawa River mouth in North Maumee Bay. The majority of drum larvae captured in Maumee Bay (87% of species total) were developed beyond the pro-larvae stage. Drum larvae are extremely bouyant and easily carried by currents. Snyder (1978) reported drum densities in the Maumee River estuary in excess of 500 per 100 m³. Therefore, many of the drum larvae captured in the bay may have been carried there from the lower Maumee River estuary.

Densities of yellow perch larvae were higher off Otter Creek, Michigan (transect M2) than anywhere else in the study area. The reason for this high concentration of larvae is not obvious examining the habitat in the area. However, the dominant summer surface currents shown in Figure 1 depict that the intersection of currents from the Maumee and Detroit Rivers results in an eddy in this area. This eddy effect has been demonstrated to concentrate pollutants here (U.S. Dept. of Interior, 1967). Therefore the high concentrations of perch larvae found along transect M2 may have resulted from larvae being transported from Maumee Bay and from along the Michigan shoreline. Overall, yellow perch and walleye larvae densities were higher along the Ohio shoreline than anywhere in the study area. The spawning habitat found here, consisting of a sand and gravel bottom, and off-shore rock shoals is perhaps the best to be found in the U.S. waters of Lake Erie for walleye and yellow perch.

Central Basin

In 1978, 21 taxa of larval fishes were captured along the shoreline of the Ohio portion of the Central Basin. The bulk of the catch was made up of cyprinid fishes, with emerald and spottail shiners contributing 32% and 16% of the total catch respectively. Cleupids, mainly gizzard shad, ranked second, making up 30% of the total. Volume weighted estimates of production indicated 54% of all larvae in the nearshore zone were emerald shiner. Species of commercial and/or sport interest captured were rainbow smelt, carp, white bass, yellow perch, sauger and walleye. The capture of walleye and sauger was limited to only a few specimens at a limited number of locations.

No rainbow smelt spawning activity has been reported in the study area. Historically it has been believed that any smelt larvae found in the area were probably spawned in the Pelee Island-Long Point area and drifted into the study area with surface currents flowing southward from Pelee Passage to the Ohio shoreline (Figure 1) (MacCallum and Regier, 1969). The fact that 72% of the larvae were captured well offshore and that over 98% of the catch was made up of smelt developed beyond the pro-larval stage indicates that most of the larvae captured were probably carried into the study area by these currents. On July 17 pro-larvae smelt were captured at Station 1/1 near Sandusky at a calculated density of 14.25 larvae per 100 m³, suggesting that smelt spawn in the sandy shallows along Cedar Point.

perch. Maximum density of larval yellow perch sampled was 48.5 larvae per 100 m³ on June 19 at Station 9/1.

Log Perch

With a basin-wide average density of .74 larvae per 100 m³, log perch were the tenth most abundant species captured. Log perch larvae were first captured on May 19 and were captured during every sampling effort thereafter. Samples collected indicated log perch densities were highest on May 25 with a mean basin density of 2.01 larvae per 100 m³ (Figure 45).

The distribution of log perch larvae throughout the study area was rather uniform (Figure 46). No statistical differences in densities were detectable between depth zones (Friedman's Rank Sum $\alpha=.05$, $df=2$) or between transects (Friedman's $\alpha=.05$, $df=9$). Maximum density of log perch sampled was 14.82 larvae per 100 m³ at Station 5/1 on June 26.

Freshwater Drum

With a basin-wide average density of 3.92 larvae per 100 m³ freshwater drum were the fourth most abundant larval species captured in the Central Basin in 1978. Larval drum were first captured on May 25 and were captured during every sampling effort thereafter. Samples collected indicated drum larvae were most abundant on July 18 with a mean basin density of 23.8 larvae per 100 m³ (Figure 47).

The distribution of drum larvae was almost limited to the area west of Cleveland, with 86.7% of the total drum catch coming from transects 1-4 (Figure 48). Friedman's Rank Sum Test ($\alpha=.05$, $df=8$) demonstrated significant differences between the transects west of and those east of Cleveland. No significant differences could be detected between onshore and offshore densities. Maximum density of larval drum sampled was 40.1 larvae per 100 m³ at Station 4/3 on July 18.

POWER PLANT ENTRAINMENT

Western Basin and Estuaries, 1975-1976

The two principal power plants located within the 1975-1976 study area were Toledo Edison's Davis-Besse Nuclear Power Plant and the Bayshore Power Plant. Sufficient data was developed from the 1975-1976 larval fish collections to permit the use of Goodyear's (1978) equivalent adult approach to estimate the impact of entrainment on yellow perch (Appendix C) and emerald shiner (Appendix C). These calculations estimate the loss of approximately 192,704 three-year old yellow perch due to entrainment (assuming 100 percent mortality: 127,184 assuming 66 percent mortality) at the Bayshore Plant in 1975. Entrainment at this facility in 1976 would result in the loss of 36,306 (23,962, 66% mortality) three-year-old fish. Calculation of entrainment losses at the Davis-Besse facility in 1976 were lower, 949 fish. The small number at Davis-Besse is due to the reduced demand for cooling water at a facility with a large cooling tower. It must be borne in mind that these are undoubtedly underestimates due to daylight/large mesh net sampling methods and the use of an average density

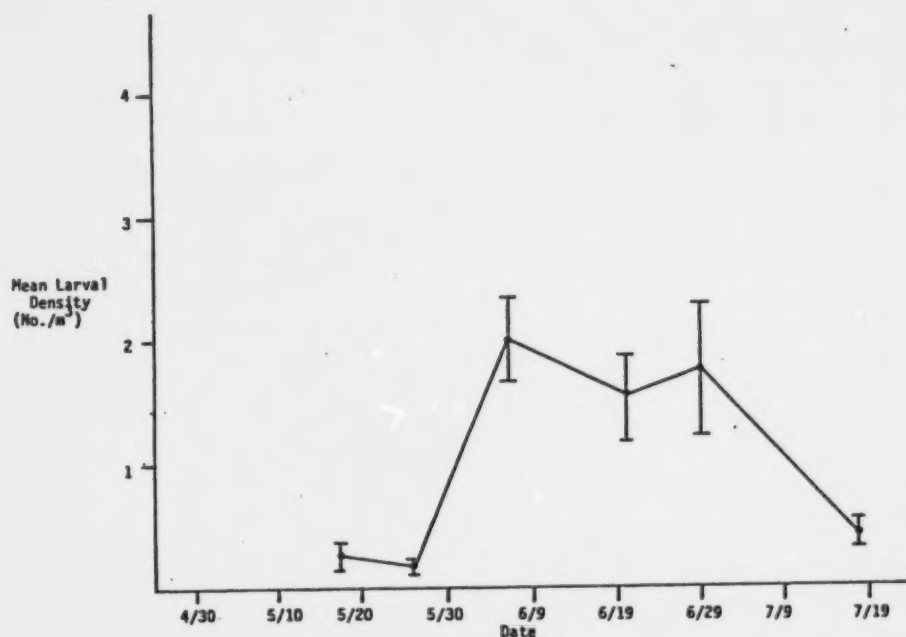


Figure 45. Mean Density of Log Perch in the Central Basin During 1978.
Distance between bars represents one standard error of the mean.

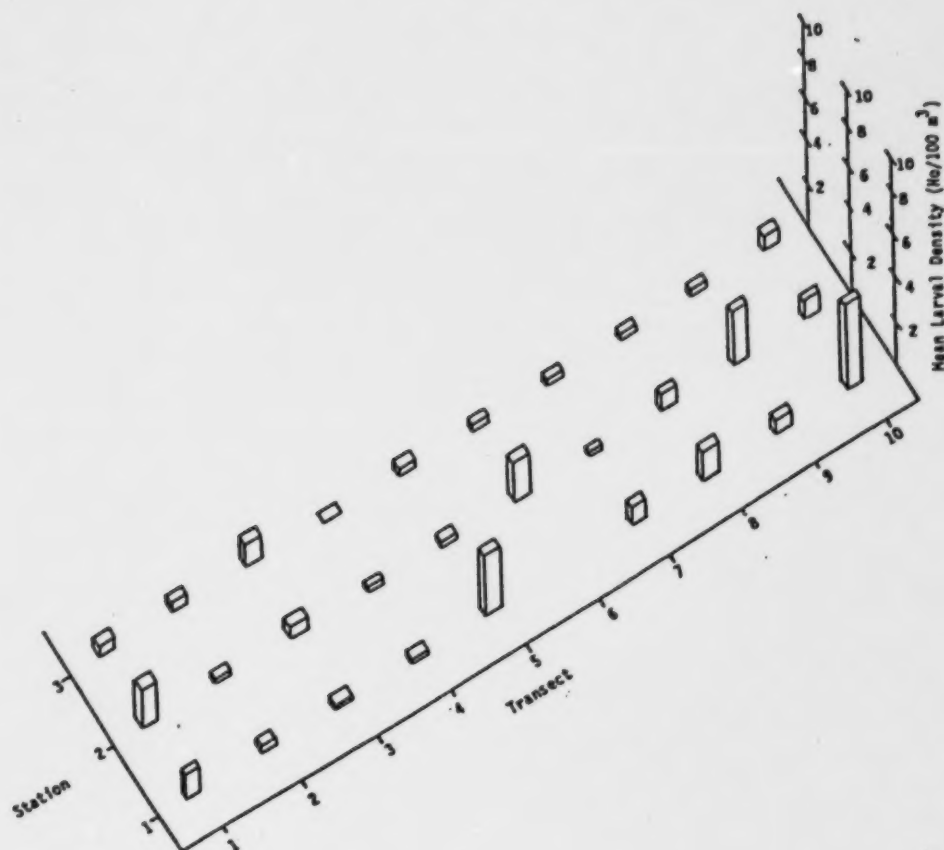


Figure 46. Central Basin - 1978.
Mean Density of Log Perch Larvae at Each Station.

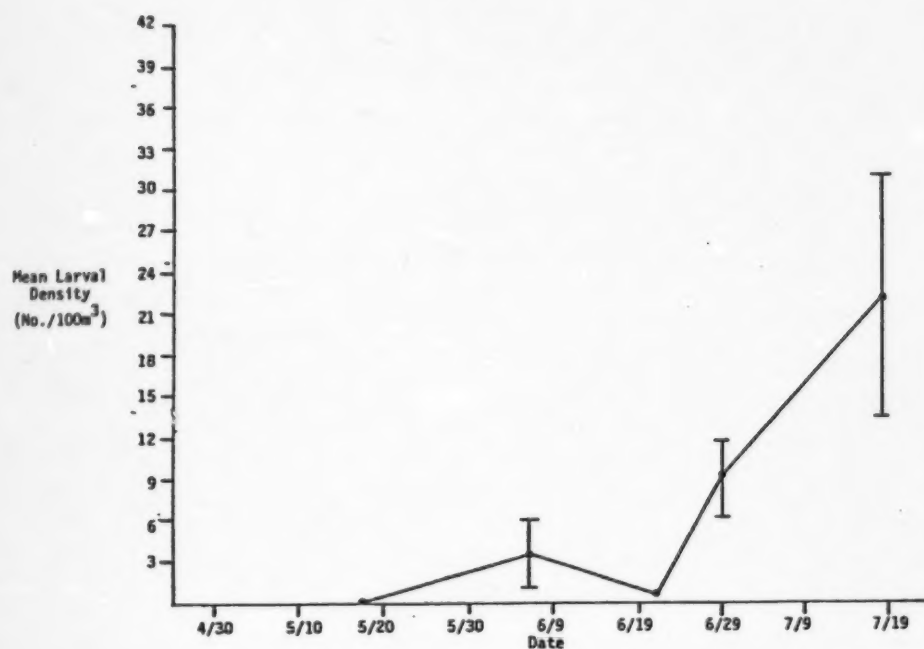


Figure 47. Mean Density of Freshwater Drum Larvae in the Central Basin During 1978. Distance between bars represents one standard error of the mean.

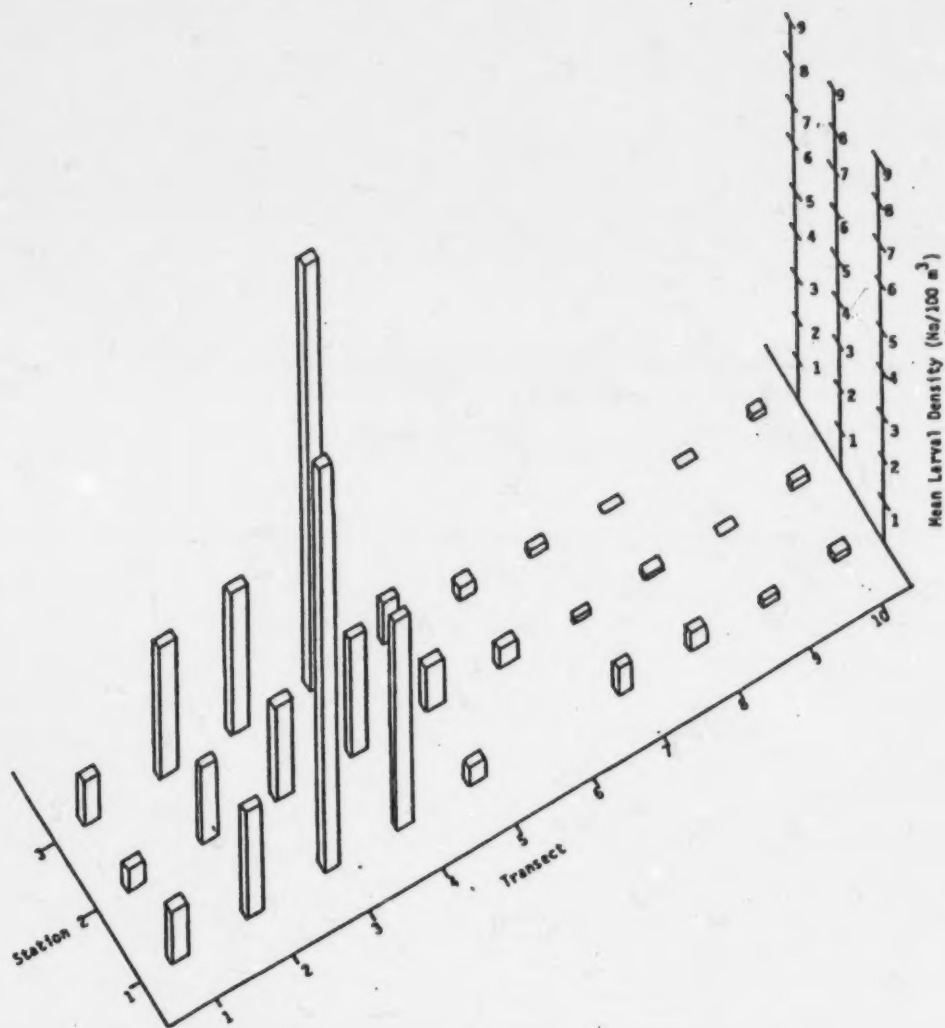


Figure 48. Central Basin - 1978.
Mean Density of Freshwater Drum Larvae at Each
Station.

value which includes data from a considerable number of offshore deep water sampling stations where yellow perch larvae were sparsely distributed or missing entirely. Calculations of the losses of one-year-old emerald shiner were considerably larger than the estimated losses of three-year-old perch.

Western Basin, 1977

In 1977, estimates of the losses of larvae at the Bayshore Power Plant and the Acme Power Plant operated by Toledo Edison Company on the Maumee River estuary were calculated by Reutter, Herdendorf and Sturm (1978a, 1978b). They estimated that approximately 2.8×10^8 larval fishes were entrained at the Bayshore Plant with clupeids and white bass representing 78.4 percent and 11.6 percent of the total, respectively. Of the 19 taxa of larval fishes collected in the Bayshore entrainment samples, only carp, freshwater drum, clupeids and white bass represented more than one percent of the total. Approximately 7.9×10^7 larval fishes were entrained at the Acme Plant with gizzard shad and freshwater drum representing 56.5 percent and 33.4 percent of the total, respectively. Of the 15 taxa collected in the Acme samples, only carp, freshwater drum, clupeids and white bass represented more than one percent of the total.

Entrainment estimates using field samples were made for four power plants along the Western Basin shoreline: the Monroe, Whiting, Bayshore and The Davis-Besse power plants (see Figure 6 for power plant locations). Clupeids were the most abundant larvae entrained, accounting for 90.54% of the total estimate of larvae entrained. Carp larvae were the second most abundant, accounting for 4.48% of the total entrained, and yellow perch were third with 2.15% of the total. Entrainment estimates were highest at the Monroe Plant where 2,965,727,308 larvae, or 60.86% of the total calculated entrainment occurred. The lowest number entrained was at Davis-Besse, 0.33% of total entrainment. The Bayshore plant entrained the largest number of yellow perch, 48% of the total number of yellow perch larvae entrained. Table 16 lists the estimated number of each species entrained at each power plant in the Western Basin. Using Bartholomew's (1979) samples collected in the vicinity of the Bayshore Power Plant intake canal and his calculated density values, we estimate between 2.2×10^6 (100% mortality and 1.4×10^6 (66% mortality) 3-year-old yellow perch were lost due to larval entrainment at this site (Appendix C) in 1977.

Central Basin, 1978

In 1978 samples were collected in the immediate area of power plant intake structures (field samples) as well as from inside the plants' screen houses (in-plant samples) at six power plants along the Ohio portion of the Central Basin; they were the Avon Lake, Edgewater, Lake Shore, Eastlake, Ashtabula A & B and Ashtabula C Plants. Paired T-tests were performed to detect differences in species composition between in-plant and field samples. No statistical differences at the $\alpha = .05$ level were detectable for any of the power plants. Paired T-tests were also used to test for differences in density of larvae between field and in-plant samples. Significant differences were detectable ($\alpha = .01$) for samples collected at the Avon Lake, East Lake, and Lake Shore plants. No additional differences were detected at $\alpha = .05$.

Entrainment estimates for each power plant were calculated using both in-plant (Table 17) and field collections (Table 18). Estimates using in-plant samples indicated Cyprinidae were the most abundant larvae entrained, accounting for 50.31% of the total (summed over all power plants), with carp (12.0% and rainbow smelt (1.7%) ranking second and third. In-plant samples estimated 3,617,717 yellow perch larvae (0.97% of the total) were entrained. Samples indicated an estimated 231,543,500 larvae entrained (137,186,000 Cyprinidae) at the Avon Lake Station, accounting for 60.1% of the total entrainment estimate in the Central Basin.

Estimates using field samples also indicated Cyprinidae were the most abundant larvae entrained, accounting for 37.21% of total entrainment in the basin. Gizzard shad (25.04%) and rainbow smelt (13.02%) ranked second and third. Samples indicated entrainment was highest at the Ashtabula A & B Plant, which entrained 76,106,800 larvae (31% of total basin entrainment). The Ashtabula A & B Plant entrained an estimated 1,703,350 yellow perch larvae, which was 37% of the total estimate of yellow perch larvae entrainment.

TABLE 16. ENTRAINMENT ESTIMATES FOR WESTERN BASIN POWER PLANTS (CALCULATED FROM FIELD COLLECTIONS)

Species	Monroe	Whiting	Bayshore	Davis-Besse	Total
Clupeids	2.70×10^9 $\pm 6.53 \times 10^8$	4.90×10^8 $\pm 8.10 \times 10^6$	1.20×10^9 $\pm 2.00 \times 10^8$	1.30×10^7 $\pm 3.21 \times 10^6$	4.40×10^9 $\pm 5.86 \times 10^8$
Whitefish	2.30×10^5 $\pm 3.83 \times 10^4$				
Rainbow Smelt	3.79×10^5 $\pm 1.10 \times 10^5$	2.98×10^6 $\pm 4.27 \times 10^5$	7.24×10^6 $\pm 1.04 \times 10^6$	1.99×10^5 $\pm 3.32 \times 10^4$	2.30×10^5 $\pm 5.74 \times 10^4$
Quillback Carp sucker		4.53×10^4 $\pm 7.56 \times 10^3$	1.10×10^5 $\pm 1.84 \times 10^4$		1.08×10^7 $\pm 1.64 \times 10^6$
Carp	2.13×10^8 $\pm 1.05 \times 10^7$	1.50×10^6 $\pm 1.64 \times 10^5$	3.65×10^6 $\pm 3.99 \times 10^5$		1.56×10^5 $\pm 2.61 \times 10^4$
Cyprinidae	2.98×10^5 $\pm 4.86 \times 10^4$	2.66×10^4 $\pm 8.79 \times 10^3$	6.46×10^4 $\pm 2.38 \times 10^4$	2.54×10^4 $\pm 4.23 \times 10^3$	2.18×10^7 $\pm 5.28 \times 10^6$
Emerald Shiner	1.53×10^7 $\pm 2.54 \times 10^6$	4.41×10^6 $\pm 7.45 \times 10^5$	1.07×10^7 $\pm 1.81 \times 10^6$	1.14×10^5 $\pm 1.89 \times 10^4$	3.89×10^5 $\pm 5.80 \times 10^7$
					3.05×10^7 $\pm 3.35 \times 10^4$

TABLE 16 (continued). ENTRAINMENT ESTIMATES FOR WESTERN BASIN POWER PLANS (CALCULATED FROM FIELD COLLECTIONS)

Species	Monroe	Whiting	Bayshore	Davis-Besse	Total
Spottail Shiner	9.36×10^5 $\pm 1.58 \times 10^5$	1.10×10^5 $\pm 3.84 \times 10^4$	2.67×10^5 $\pm 9.32 \times 10^4$		1.31×10^6 $\pm 1.05 \times 10^5$
Channel Catfish		4.90×10^3 $\pm 8.12 \times 10^2$	1.19×10^4 $\pm 1.98 \times 10^3$		1.68×10^4 $\pm 2.82 \times 10^3$
White Bass	3.31×10^6 $\pm 4.68 \times 10^5$	2.05×10^7 $\pm 2.51 \times 10^5$	4.99×10^7 $\pm 6.09 \times 10^6$	2.63×10^4 $\pm 4.24 \times 10^3$	7.37×10^7 $\pm 1.14 \times 10^7$
<u>Lepomis</u> sp.	3.10×10^5 $\pm 5.17 \times 10^4$	3.50×10^3 $\pm 1.75 \times 10^3$	8.50×10^3 $\pm 4.25 \times 10^3$		3.22×10^5 $\pm 7.65 \times 10^4$
Percidae		4.44×10^3 $\pm 7.42 \times 10^2$	1.08×10^4 $\pm 1.70 \times 10^3$		1.52×10^4 $\pm 2.55 \times 10^3$
Sauger		4.34×10^5 $\pm 4.89 \times 10^4$	1.05×10^6 $\pm 1.19 \times 10^5$		1.49×10^6 $\pm 2.49 \times 10^5$

TABLE 16 (continued). ENTRAINMENT ESTIMATES FOR WESTERN BASIN POWER PLANTS (CALCULATED FROM FIELD COLLECTIONS)

Species	Monroe	Whiting	Bayshore	Davis-Besse	Total
Walleye		5.35×10^5 $\pm 4.79 \times 10^4$	1.30×10^6 $\pm 1.16 \times 10^5$	1.22×10^5 $\pm 1.23 \times 10^4$	1.96×10^6 $\pm 2.93 \times 10^5$
Yellow Perch	3.10×10^7 $\pm 4.35 \times 10^6$	2.09×10^7 $\pm 2.06 \times 10^6$	5.07×10^7 $\pm 5.01 \times 10^6$	2.24×10^6 $\pm 6.48 \times 10^5$	1.05×10^8 $\pm 1.01 \times 10^7$
Log Perch	1.25×10^6 $\pm 6.26 \times 10^5$	1.14×10^6 $\pm 2.52 \times 10^5$	2.78×10^6 $\pm 6.11 \times 10^5$	1.15×10^5 $\pm 2.95 \times 10^4$	5.30×10^6 $\pm 5.50 \times 10^5$
Freshwater Drum		3.01×10^6 $\pm 5.76 \times 10^5$	7.32×10^6 $\pm 1.40 \times 10^6$	1.04×10^4 $\pm 1.76 \times 10^3$	1.03×10^7 $\pm 1.73 \times 10^6$
Unidentifiable		1.73×10^5 $\pm 2.75 \times 10^4$	4.21×10^5 $\pm 6.68 \times 10^4$		5.95×10^5 $\pm 9.96 \times 10^4$
Total	2.97×10^9 $\pm 1.50 \times 10^8$	5.49×10^8 $\pm 3.09 \times 10^7$	1.33×10^9 $\pm 6.62 \times 10^7$	1.58×10^7 $\pm 7.47 \times 10^5$	4.87×10^9 $\pm 2.43 \times 10^8$

TABLE 17. ENTRAINMENT ESTIMATES FOR CENTRAL BASIN POWER PLANTS
(CALCULATED FROM IN-PLANT COLLECTIONS)¹

Species	Edgewater	Avon Lake	Eastlake	Lake Shore	Ashtabula A & B	Ashtabula C	Total
<u>Coregonus</u>							
~~Coregonus~~	5.87×10^4 $\pm 4.83 \times 10^4$	2.52×10^7 $\pm 1.66 \times 10^6$	1.78×10^6 $\pm 2.37 \times 10^5$	1.42×10^6 $\pm 3.45 \times 10^5$	2.32×10^6 $\pm 2.81 \times 10^5$	2.05×10^6 $\pm 5.79 \times 10^5$	3.68×10^7 $\pm 3.90 \times 10^6$
Rainbow Smelt		2.58×10^7 $\pm 2.58 \times 10^6$	5.00×10^6 $\pm 4.15 \times 10^5$	5.93×10^6 $\pm 2.52 \times 10^5$	7.83×10^6 $\pm 7.83 \times 10^5$	8.20×10^6 $\pm 5.05 \times 10^5$	3.23×10^7 $\pm 4.16 \times 10^6$
White Sucker	7.66×10^4 $\pm 1.74 \times 10^4$	8.37×10^5 $\pm 1.39 \times 10^5$	9.28×10^5 $\pm 9.80 \times 10^4$	1.14×10^6 $\pm 1.90 \times 10^5$	7.44×10^6 $\pm 1.24 \times 10^6$		2.04×10^6 $\pm 1.73 \times 10^5$
Carp	2.78×10^5 $\pm 3.33 \times 10^4$	9.13×10^6 $\pm 1.72 \times 10^6$	1.59×10^7 $\pm 1.49 \times 10^6$	5.29×10^6 $\pm 3.46 \times 10^5$	1.46×10^7 $\pm 6.23 \times 10^6$		4.52×10^7 $\pm 2.81 \times 10^6$
Shiner	4.08×10^7 $\pm 7.84 \times 10^6$	1.30×10^8 $\pm 1.20 \times 10^7$	2.43×10^7 $\pm 2.11 \times 10^6$	1.02×10^8 $\pm 1.69 \times 10^7$	1.30×10^7 $\pm 6.20 \times 10^6$	1.20×10^8 $\pm 5.48 \times 10^7$	2.09×10^8 $\pm 1.83 \times 10^7$
Minnow	2.57×10^6 $\pm 3.96 \times 10^5$	7.66×10^6 $\pm 3.49 \times 10^6$	9.75×10^6 $\pm 8.07 \times 10^6$	7.79×10^6 $\pm 5.64 \times 10^6$	1.14×10^7 $\pm 9.97 \times 10^6$	5.04×10^6 $\pm 8.04 \times 10^5$	3.22×10^7 $\pm 1.98 \times 10^6$
Bluntnose Minnow		7.17×10^5 $\pm 3.31 \times 10^5$					7.17×10^5 $\pm 1.19 \times 10^5$
Burbot		2.42×10^5 $\pm 2.42 \times 10^4$					2.42×10^5 $\pm 4.03 \times 10^4$
Trout Perch	4.18×10^5 $\pm 6.97 \times 10^4$	3.22×10^6 $\pm 6.75 \times 10^5$	3.85×10^6 $\pm 3.27 \times 10^5$	1.92×10^6 $\pm 1.75 \times 10^5$	7.12×10^6 $\pm 1.19 \times 10^6$	1.04×10^6 $\pm 1.40 \times 10^5$	5.03×10^6 $\pm 4.42 \times 10^5$
White Bass					2.00×10^6 $\pm 3.32 \times 10^5$		2.00×10^6 $\pm 3.32 \times 10^5$
<u>Lepomis</u> sp.	1.96×10^5 $\pm 2.45 \times 10^4$	2.78×10^6 $\pm 2.78 \times 10^5$				6.80×10^6 $\pm 6.80 \times 10^5$	2.92×10^6 $\pm 3.14 \times 10^5$
<u>Micropterus</u> sp.				1.70×10^6 $\pm 2.83 \times 10^5$			1.70×10^6 $\pm 2.83 \times 10^5$
Percidae			3.85×10^6 $\pm 3.27 \times 10^5$		4.54×10^6 $\pm 2.57 \times 10^5$		8.40×10^6 $\pm 8.90 \times 10^5$
Sauger	2.09×10^5 $\pm 3.48 \times 10^4$						2.09×10^5 $\pm 3.48 \times 10^4$
Walleye					3.71×10^6 $\pm 6.18 \times 10^5$	6.35×10^6 $\pm 6.35 \times 10^5$	4.34×10^6 $\pm 6.06 \times 10^5$
Yellow Perch		1.35×10^6 $\pm 1.31 \times 10^5$	7.02×10^6 $\pm 7.61 \times 10^5$		1.32×10^6 $\pm 1.42 \times 10^5$	2.59×10^6 $\pm 3.47 \times 10^5$	3.62×10^6 $\pm 2.48 \times 10^5$
Log Perch	3.83×10^5 $\pm 3.12 \times 10^4$	3.33×10^6 $\pm 2.09 \times 10^5$	2.55×10^6 $\pm 1.06 \times 10^6$	6.76×10^6 $\pm 1.01 \times 10^6$	1.08×10^6 $\pm 6.71 \times 10^5$	1.26×10^6 $\pm 4.67 \times 10^5$	8.15×10^6 $\pm 5.27 \times 10^5$
Freshwater Drum	1.97×10^5 $\pm 3.69 \times 10^4$	4.10×10^6 $\pm 8.75 \times 10^5$		1.14×10^6 $\pm 1.73 \times 10^5$			7.20×10^6 $\pm 6.66 \times 10^5$
Mottled Sculpin		2.17×10^6 $\pm 3.62 \times 10^5$			8.21×10^6 $\pm 1.37 \times 10^6$		2.99×10^6 $\pm 3.60 \times 10^5$
Unidentifiable		2.44×10^7 $\pm 1.79 \times 10^6$	1.76×10^7 $\pm 1.39 \times 10^6$	1.42×10^6 $\pm 1.35 \times 10^5$	4.97×10^6 $\pm 1.47 \times 10^6$	9.17×10^6 $\pm 9.35 \times 10^5$	4.93×10^7 $\pm 4.19 \times 10^6$
Total	5.06×10^7 $\pm 3.81 \times 10^6$	2.33×10^8 $\pm 6.50 \times 10^6$	7.93×10^7 $\pm 1.60 \times 10^6$	1.09×10^7 $\pm 2.70 \times 10^5$	5.07×10^7 $\pm 1.36 \times 10^6$	3.81×10^6 $\pm 1.22 \times 10^5$	4.28×10^8 $\pm 3.13 \times 10^7$

¹Lower number in each cell is equal to one standard error of the mean.

TABLE 18. ENTRAINMENT ESTIMATES FOR CENTRAL BASIN POWER PLANTS
(CALCULATED FROM FIELD COLLECTIONS)¹

Species	Edgewater	Avon Lake	Eastlake	Lake Shore	Ashtabula A & B	Ashtabula C	Total
Clupeid	7.91×10^4 $\pm 2.03 \times 10^4$	2.38×10^7 $\pm 3.44 \times 10^4$	9.21×10^4 $\pm 2.60 \times 10^4$	4.77×10^4 $\pm 8.60 \times 10^4$	1.01×10^7 $\pm 2.90 \times 10^4$	5.60×10^4 $\pm 1.75 \times 10^4$	6.14×10^7 $\pm 2.59 \times 10^4$
Rainbow Smelt	2.91×10^4 $\pm 1.54 \times 10^4$	1.27×10^4 $\pm 1.53 \times 10^4$	2.19×10^7 $\pm 3.44 \times 10^4$	9.33×10^4 $\pm 1.03 \times 10^4$	4.46×10^4 $\pm 3.40 \times 10^4$	3.06×10^4 $\pm 3.88 \times 10^4$	3.19×10^7 $\pm 3.08 \times 10^4$
Carp	4.78×10^4 $\pm 1.18 \times 10^4$		4.17×10^4 $\pm 1.39 \times 10^4$	2.70×10^4 $\pm 2.42 \times 10^4$	1.36×10^4 $\pm 2.26 \times 10^4$	1.34×10^4 $\pm 2.24 \times 10^4$	5.09×10^4 $\pm 3.81 \times 10^4$
Cyprinidae	4.14×10^4 $\pm 6.90 \times 10^4$						4.14×10^4 $\pm 6.30 \times 10^4$
Emerald Shiner	9.73×10^4 $\pm 2.10 \times 10^4$	7.44×10^4 $\pm 1.65 \times 10^4$	1.33×10^7 $\pm 2.91 \times 10^4$	2.39×10^4 $\pm 7.02 \times 10^4$	3.18×10^7 $\pm 8.69 \times 10^4$	3.09×10^7 $\pm 6.76 \times 10^4$	8.01×10^7 $\pm 5.48 \times 10^4$
Spottail Shiner	2.48×10^4 $\pm 5.52 \times 10^4$	1.12×10^4 $\pm 2.91 \times 10^4$	5.82×10^4 $\pm 5.84 \times 10^4$	5.45×10^4 $\pm 7.45 \times 10^4$	4.11×10^4 $\pm 8.68 \times 10^4$	3.32×10^4 $\pm 1.50 \times 10^4$	1.12×10^7 $\pm 9.20 \times 10^4$
Burbot					7.70×10^4 $\pm 1.28 \times 10^4$	7.20×10^4 $\pm 1.20 \times 10^4$	1.49×10^4 $\pm 1.43 \times 10^4$
Trout Perch			2.20×10^4 $\pm 3.56 \times 10^4$	9.44×10^4 $\pm 1.19 \times 10^4$	2.37×10^4 $\pm 2.05 \times 10^4$	3.39×10^4 $\pm 1.55 \times 10^4$	5.85×10^4 $\pm 4.00 \times 10^4$
White Bass	9.43×10^4 $\pm 1.57 \times 10^4$						9.43×10^4 $\pm 1.40 \times 10^4$
<u>Lepomis</u> sp.						2.88×10^4 $\pm 4.80 \times 10^4$	2.88×10^4 $\pm 4.38 \times 10^4$
Percidae		1.40×10^4 $\pm 2.35 \times 10^4$	6.72×10^4 $\pm 1.12 \times 10^4$		3.18×10^4 $\pm 5.29 \times 10^4$	4.24×10^4 $\pm 7.07 \times 10^4$	3.81×10^4 $\pm 4.68 \times 10^4$
Walleye			7.65×10^4 $\pm 1.28 \times 10^4$	4.05×10^4 $\pm 4.75 \times 10^4$			1.17×10^4 $\pm 1.20 \times 10^4$
Yellow Perch	4.83×10^4 $\pm 8.05 \times 10^4$	9.84×10^4 $\pm 3.61 \times 10^4$	8.57×10^4 $\pm 1.59 \times 10^4$	1.10×10^4 $\pm 1.89 \times 10^4$	1.70×10^4 $\pm 1.57 \times 10^4$	7.94×10^4 $\pm 1.98 \times 10^4$	4.60×10^4 $\pm 2.33 \times 10^4$
Log Perch	2.65×10^4 $\pm 1.07 \times 10^4$	2.53×10^4 $\pm 4.11 \times 10^4$		2.06×10^4 $\pm 3.82 \times 10^4$	2.34×10^4 $\pm 1.57 \times 10^4$	1.50×10^4 $\pm 1.97 \times 10^4$	5.07×10^4 $\pm 3.94 \times 10^4$
Johnny Darter					6.08×10^4 $\pm 1.12 \times 10^4$	7.92×10^4 $\pm 1.35 \times 10^4$	1.40×10^7 $\pm 1.36 \times 10^4$
Freshwater Drum	4.30×10^4 $\pm 1.97 \times 10^4$	1.03×10^7 $\pm 5.13 \times 10^4$	1.26×10^4 $\pm 2.10 \times 10^4$	7.03×10^4 $\pm 5.25 \times 10^4$	8.81×10^4 $\pm 2.37 \times 10^4$	2.08×10^4 $\pm 2.52 \times 10^4$	1.26×10^7 $\pm 1.50 \times 10^4$
Mottled Sculpin					7.69×10^4 $\pm 3.84 \times 10^4$	1.26×10^4 $\pm 6.05 \times 10^4$	8.95×10^4 $\pm 1.15 \times 10^4$
Unidentifiable	1.51×10^4 $\pm 2.51 \times 10^4$						1.51×10^4 $\pm 2.30 \times 10^4$
Total	1.18×10^7 $\pm 4.21 \times 10^4$	3.67×10^7 $\pm 1.36 \times 10^4$	5.40×10^7 $\pm 1.38 \times 10^4$	1.62×10^7 $\pm 3.00 \times 10^4$	7.61×10^7 $\pm 1.71 \times 10^4$	5.12×10^7 $\pm 1.68 \times 10^4$	2.52×10^8 $\pm 8.59 \times 10^4$

¹Lower number in each cell is equal to one standard error of the mean.

SECTION 6

DISCUSSION

SPECIES DISTRIBUTION

Before one can attempt to predict the effects of power plant entrainment on fish populations, or before intake structures for proposed power plant locations can be located, such that losses due to entrainment are minimized, the spatial and temporal distributions of fish larvae in the area must be accurately described. Graphical depictions, as well as verbal summaries have been presented to provide insight into the spatial and temporal distributions of fish larvae commonly found in the Western Basin of Lake Erie in 1975-1977 and in the Central Basin in 1978. A discussion of the major distributional findings follows.

Western Basin

In 1977, 20 taxa of larval fishes were collected along the near-shore zone of the Western Basin. Larval clupeids, principally gizzard shad, were the most abundant species collected, comprising 87% of the total larval catch. Species of sport and/or commercial interest collected were rainbow smelt, whitefish, carp, white bass, yellow perch, sauger, walleye and freshwater drum.

Larval whitefish and sauger, although rarely captured, are of significance. Both whitefish and sauger were abundant and commercially fished throughout the 1950's. Populations of these two species were reduced to the point that only rarely were whitefish or sauger captured. Efforts have been made through stocking programs to re-establish the native sauger population. The capture of larval sauger in this study indicated these efforts may have been successful. The capture of whitefish larvae indicated a small population of whitefish still uses spawning sites in the Western Basin.

Although rainbow smelt were commonly captured in the Western Basin, very few pro-larval smelt were found. This indicates smelt larvae were carried into the study area by currents, possibly by the Detroit River.

Littoral areas, i.e., quiet areas of bays and harbors, or slowly moving rivers and streams, are preferred as spawning habitat by carp. Large numbers of carp larvae were captured with highest densities of carp in samples taken at the intake of the Detroit Edison power plant near the mouth of the River Raisin. The majority of carp found in Lake Erie were probably spawned in tributaries and harbors.

Both white bass and freshwater drum larvae were found to be significantly more abundant in the estuaries and adjacent bays than along either the Michigan or Ohio shorelines or the open water portions of

Sheltered habitat found in the large harbors of the Central Basin are ideal for carp. Large catches of carp larvae were made in these harbors. Although one of the major commercial species in Lake Erie, carp are usually held in low regard and few, if any, management decisions are developed around protecting carp.

The vast majority of freshwater drum larvae were collected in the western-third of the Central Basin study area, with 87% of the catch coming from Transects 1-4. Although drum are reported as pelagic spawners, adult drum usually inhabit water less than 12 meters deep. The area west of Cleveland, where most of the drum larvae were captured, contains a larger band of relatively shallow water than the area east of Cleveland. East of Cleveland, water less than 12 meters deep is limited to a very narrow band along the shoreline.

Yellow perch are the species of main concern in the Central Basin of the lake. Perch larvae were found to be concentrated mostly along the shore, particularly in the eastern-third of the study area. Yellow perch deposit their eggs in ribbon-like tubes in debris, aquatic vegetation, or on clean gravel or sand. The area where the majority of yellow perch larvae were captured has very limited quantities of clean gravel and sand, and even less aquatic vegetation. Yellow perch, therefore, appear to be using the harbor breakwalls and the sand accumulated on the lee-side of these structures as spawning habitat.

POWER PLANT ENTRAINMENT

Western Basin

Numbers of larval fishes entrained were estimated for four power plants along the shoreline of the Western Basin (Table 16). Estimates were obtained by multiplying average larval concentrations at the station(s) most immediately adjacent to the cooling water intake structures by the pumping rates reported by each plant. Calculations indicate 4.4×10^9 clupeid larvae were entrained at the four plants. This represented 90.3% of total larval entrainment. Carp were the second most frequently entrained larvae, representing 4.4% of the total. Yellow perch (2.2% of total) and walleye (0.04% of total) ranked third and eleventh, respectively, in numbers entrained.

Estimates of larval abundance in three depth zones of the nearshore zone of the Western Basin were also calculated (see Appendix C). The combined estimated fish entrainment at the four power plants is presented in Table 19. Table 19 shows a comparison of nearshore production vs. entrainment in an effort to quantify the effect of the power plants on larval fish populations in the nearshore zone. This comparison suggests that for several species, entrainment estimates approach, nearshore abundance estimates, indicating sources of larval fish beyond the limits of the study area.

TABLE 19. TOTAL ENTRAINMENT ESTIMATES OF FOUR WESTERN BASIN POWER PLANTS DURING THE 1977 SAMPLING PERIOD

Species	NEARSHORE PRODUCTION	ENTRAINMENT ESTIMATE	PERCENT ENTRAINED
Clupeid	1.30×10^{10}	4.40×10^9	33.85
Whitefish	2.32×10^6	2.30×10^5	9.90
Rainbow Smelt	6.34×10^7	1.08×10^7	17.00
Quillback Carpsucker	7.65×10^5	1.56×10^5	20.00
Carp	1.64×10^8	2.18×10^7	13.3
Emerald Shiner	5.16×10^8	3.05×10^7	5.90
Spottail Shiner	1.27×10^7	1.31×10^6	10.30
Channel Catfish	6.69×10^5	1.68×10^4	2.50
White Bass	2.65×10^8	7.37×10^7	27.80
Lepomis sp.	4.12×10^6	3.22×10^5	7.82
Percidae	2.66×10^5	1.52×10^4	5.70
Sauger	2.25×10^6	1.49×10^6	66.20
Walleye	6.08×10^7	1.96×10^6	3.20
Yellow Perch	1.35×10^9	1.05×10^8	7.80
Log Perch	6.82×10^7	5.30×10^6	7.80
Freshwater Drum	1.42×10^8	1.03×10^7	7.30

Both entrainment estimates and estimated larval production in the nearshore zone are believed to be accurate within the limits associated with the sampling program. However, no attempt was made to estimate the input of larvae from the tributaries during the 1977 study period. Snyder (1978) estimated abundance of gizzard shad, freshwater drum, and white bass in a 14 km² area extending from the mouth of the Maumee River to the head of the Maumee estuary to rival if not exceed the estimate of abundance of these species in a 1740 km² portion of the Western Basin proper studied by Heniken (1977) in 1975 and 1976.

Reutter et al. (1978a, 1978b) examined larvae abundance in a portion of the lower Maumee River estuary during the 1977 sampling season. Comparison of nearshore production estimates reported herein with Reutter's abundance estimates in the Maumee estuary leads to a conclusion similar to that of Snyder (1978), in that the estuary is a major larvae production area. This conclusion is evident in numbers presented in Table 20. The white bass production estimate at the mouth of the Maumee River was two times greater than that of the nearshore study area. Freshwater drum production in the Maumee estuary clearly exceeded that from the lake. It is suggested that the large number of drum larvae in the Maumee River is partially responsible for the high densities of drum larvae occurring in Maumee Bay. While not exceeding the nearshore production, clupeid, largely gizzard shad larvae were very abundant in the Maumee River. In contrast, estimates of yellow perch and emerald shiner larvae occur predominantly in nearshore areas of the lake. The latter species are comparatively infrequent in the Maumee River estuary area studied by Reutter.

Although comparisons of nearshore production estimates have been made, very clear incongruities are evident. These comparisons can be used only with great care, realizing the inherent bias resulting from unmeasured estuarine inputs.

A total of 4.87×10^9 larvae were estimated to have been entrained by the four power stations along the shoreline of the Western Basin in 1977. An estimated 2.97×10^9 (61% of the total) larvae were entrained at Detroit Edison's Monroe Plant. Toledo Edison's Bayshore plant ranked second in total entrainment, accounting for 27.3% of the total. Consumers Power Whiting Plant and the Toledo Edison-operated Davis-Besse Nuclear Power Plant accounted for 11.3 and 0.3%, respectively, of the total entrainment.

Entrainment estimates indicated clupeid larvae were by far the most numerous larvae entrained at all the power plants. Clupeid larvae represented between 91% of the total entrainment at Monroe to 82% at Davis-Besse (Table 21). Carp/Goldfish larvae represented 7.2% of the total entrainment at Monroe. The latter is a far greater percentage than calculated for the three other facilities. The River Raisin and the immediately adjacent wetland areas undoubtedly contribute the greater proportion of carp larvae entrained at the Monroe facility.

TABLE 20. COMPARISON OF NEARSHORE AND ESTUARINE PRODUCTION ESTIMATES
DURING THE 1977 STUDY PERIOD

Species		Production Estimates	
Nearshore/ Estuarine Species	Nearshore Estimate	Maumee River Mouth Estimate	Maumee River Estuary Estimate
White Bass	2.65×10^8	5.6×10^8	1.15×10^8
Freshwater Drum	1.42×10^8	1.4×10^8	1.43×10^9
Gizzard Shad	1.30×10^{10}	6.5×10^9	1.30×10^9
Nearshore Species			
Yellow Perch	1.35×10^9	1.30×10^7	4.60×10^6
Emerald Shiner	5.16×10^8	1.20×10^6	1.90×10^5

TABLE 21. ESTIMATES OF THE RELATIVE ABUNDANCE OF FISH SPECIES ENTRAINED AT EACH OF FOUR WESTERN LAKE ERIE POWER PLANTS DURING THE 1977 STUDY PERIOD

Species	Monroe (%)	Whiting (%)	Bayshore (%)	Davis-Besse (%)	All Power Plants (%)
Clupeid	90.90	89.31	90.23	82.01	90.31
Whitefish	0.08				0.05
Rainbow Smelt	0.13	0.54	0.54	1.30	0.22
Quillback		0.01	0.01		0.01
Carp sucker					
Carp/Goldfish	7.20	0.27	0.27	0.16	4.40
Cyprinidae	0.01	0.05	0.03		0.08
Emerald Shiner	0.05	1.20	0.80	0.72	0.63
Spottail Shiner	0.03	0.02	0.02		0.03
Channel Catfish		0.01	0.01		
White Bass	0.01	3.73	3.75	0.17	1.50
Lepomis sp.	0.01	0.01	0.01		0.01
Percidae		0.01	0.01		0.01
Sauger		0.08	0.08		0.03
Walleye		0.10	0.10	0.77	0.04
Yellow Perch	1.04	3.80	3.81	1.41	2.20
Log Perch	0.04	0.21	0.21	0.73	
Freshwater Drum		0.55	0.55	0.07	
Unidentifiable		0.15	0.03		
Total	100.00	100.00	100.00	100.00	100.00

The number of carp entrained here was larger than the nearshore abundance estimate. Protected littoral habitat along the River Raisin estuary and the Maumee River estuary provide spawning habitat for fish species preferring shallow, quiet waters.

Although entrainment at the Monroe facility accounted for 61% of the total entrainment, a relatively small percentage of commercial and sport fishes were entrained here. Of the larval yellow perch entrained, 48.3% were entrained at Toledo Edison's Bayshore Plant, while the larger Monroe Plant entrained only 30%. Entrainment of larval sauger and freshwater drum occurred only at the Bayshore and Whiting Plants. Entrainment of larval walleye was largely limited to the Bayshore and Whiting Plants with 6.2% of walleye entrainment occurring at the Davis-Besse Plant. Table 22 provides percentage of the total entrainment estimate for each species at each power plant.

Central Basin

Entrainment estimates were calculated for six power plants located along the Ohio shoreline of the Central Basin. Separate estimates were developed using in-plant collections as well as field collections of larvae. Basin-wide entrainment estimates derived from in-plant and field collections did not differ statistically when summed over all species (Wilcoxon's Signed-Rank Test; $\alpha = .05$). However, when species-by-species or plant-by-plant comparisons were made, statistical differences between field and in-plant estimates were often found. Statistical differences were found between entrainment estimates, summed over all power plants, for clupeids, white suckers, carp, and freshwater drum (Wilcoxon's Signed Rank Test; $\alpha = .05$) (Table 23). Entrainment estimates derived from field samples for carp, and drum were significantly higher than estimates derived from in-plant samples. Clupeid and white sucker estimates were statistically higher when derived from in-plant samples. Estimates of entrainment derived from field and in-plant collections, summed over all species, were significantly different for the Avon Lake Plant and the Ashtabula C Plant (Wilcoxon's Signed Rank Test; $\alpha = .05$). Estimates of entrainment were higher for in-plant samples at the Avon Lake Plant and from field samples at the Ashtabula C Plant.

Entrainment estimates developed from field collections indicated a total of 2.52×10^8 larvae were entrained by Central Basin power plants in 1978 (Table 18). Emerald shiner larvae were the most frequently entrained species (31.79% of the total). Clupeid and rainbow smelt larvae ranked second and third representing 24.36 and 12.66% of the total entrainment, respectively. A total of 4.60×10^6 yellow perch larvae (1.83% of the total) and 1.17×10^5 walleye larvae (.05% of the total) were calculated to have been entrained.

Entrainment estimates derived from field collections were compared with estimated larval abundance in the Central Basin nearshore zone. Table 24 contains the percentage of the estimated

TABLE 22. ESTIMATE OF THE PERCENTAGE OF TOTAL ENTRAINMENT BY SPECIES AT EACH OF FOUR LAKE ERIE WESTERN BASIN POWER PLANTS DURING THE 1977 STUDY PERIOD

Species	Monroe (%)	Whitting (%)	Bayshore (%)	Davis-Besse (%)	Total
Clupeid	61.0	11.0	27.0	1.00	4.40×10^9
Whitefish	100.0				2.30×10^5
Rainbow Smelt	3.5	27.6	67.0	1.80	1.08×10^7
Quillback Carp sucker		27.0	73.0		1.56×10^5
Carp	97.7	0.7	1.6	0.01	2.18×10^7
Emerald Shiner	50.0	14.0	35.0	1.00	3.05×10^7
Spottail Shiner	71.0	8.4	20.4	0.20	1.31×10^6
White Bass	4.5	27.8	67.7	0.01	7.37×10^7
<u>Lepomis</u> sp.	96.3	1.1	2.6		3.22×10^5
Percidae		29.2	70.8		1.52×10^6
Sauger		29.1	70.9		1.49×10^6
Walleye		27.3	66.3	6.20	1.96×10^6
Yellow Perch	29.5	19.9	48.3	2.10	1.05×10^8
Log Perch	23.6	21.5	52.50	2.2	5.30×10^6
Freshwater Drum		29.0	71.0		1.03×10^7

TABLE 23. COMPARISON OF RELATIVE ABUNDANCE OF ESTIMATED ENTRAINED SPECIES.
IN-PLANT VS. FIELD SURVEYS

SPECIES	IN-PLANT ESTIMATES		FIELD ESTIMATES		DIFFERENCE ¹
	NUMBER ENTRAINED	% OF TOTAL	NUMBER ENTRAINED	% OF TOTAL	
Clupeid	3.68×10^7	11.30	6.14×10^7	24.36	-2.46×10^7
Rainbow Smelt	3.23×10^7	9.92	3.19×10^7	12.66	4.00×10^5
White Sucker	2.03×10^6	0.62	0	0	2.03×10^6
Carp/Goldfish	4.52×10^7	13.88	5.09×10^6	2.01	4.01×10^7
Shiner & Minnow	1.88×10^8	57.74	9.13×10^7	36.23	9.67×10^7
Emerald & Spottail Shiner					
Bluntnose Minnow	7.17×10^5	0.22	0	0	7.17×10^5
Burbot	2.42×10^5	0.07	1.49×10^5	0.06	9.30×10^4
Trout Perch	4.66×10^6	1.43	5.85×10^6	2.32	-1.19×10^6
White Bass	2.00×10^5	0.06	9.43×10^4	0.04	1.06×10^5
<u>Lepomis</u> sp.	2.92×10^5	0.09	2.88×10^4	0.01	2.63×10^5
<u>Micropterus</u> sp.	1.70×10^5	0.05	0	0	1.70×10^5
Percidae	1.40×10^5	0.26	3.81×10^6	1.51	-2.97×10^6
Sauger	2.09×10^4	0.01	0	0	2.09×10^4
Walleye	4.34×10^5	0.14	1.16×10^5	0.05	3.18×10^5
Yellow Perch	3.62×10^6	1.11	4.60×10^6	1.83	-9.80×10^5
Log Perch	4.85×10^6	1.49	5.07×10^6	2.01	-2.20×10^5
Johnny Darter	0	0	1.40×10^7	5.56	-1.40×10^7
Freshwater Drum	7.20×10^5	0.22	1.27×10^7	5.04	-1.20×10^7
Mottled Sculpin	2.99×10^5	0.09	8.95×10^6	3.55	-8.61×10^6
Unidentifiable (Damaged) Larvae	4.19×10^6	1.29	1.51×10^5	0.06	4.04×10^6
Total	3.26×10^8		2.52×10^8		7.40×10^7

¹Negative values indicate larger estimates from field samples.
Positive values indicate larger estimates from in-plant samples.

TABLE 24. ESTIMATE OF THE PERCENTAGE OF TOTAL ENTRAINMENT BY SPECIES AT EACH OF SIX CENTRAL BASIN POWER PLANTS (Estimated from Field Collections)

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)	Total
Clupeid	12.88	38.76	15.00	7.77	16.44	9.12	6.14×10^7
Rainbow Smelt	0.91	3.98	68.65	2.92	13.98	9.59	3.19×10^7
Carp/Goldfish	9.39	..	8.19	53.04	26.72	2.60	5.09×10^6
Cyprinidae	100.00						4.14×10^4
Emerald Shiner	1.21	0.93	16.60	2.99	39.70	38.58	8.01×10^7
Spottail Shiner	2.20	1.09	51.20	4.87	36.70	2.96	1.12×10^7
Burbot					51.67	48.32	1.49×10^5
Trout Perch			37.61	16.14	40.51	5.79	5.85×10^5
White Bass	100.00						9.43×10^5
<u>Lepomis sp.</u>						100.00	2.88×10^4

TABLE 24 (continued). ESTIMATE OF THE PERCENTAGE OF TOTAL ENTRAINMENT BY SPECIES AT EACH OF SIX CENTRAL BASIN POWER PLANTS (Estimated from Field Collections)

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)	Total
Percidae							
Walleye		3.67	1.76		83.46	11.13	3.81×10^6
Yellow Perch	1.05		65.38	34.62			1.17×10^5
Log Perch	5.23	2.14	18.63	23.91	36.96	17.26	4.60×10^6
Johnny Darter		4.99		40.63	46.15	2.96	5.07×10^6
Freshwater Drum	3.41	81.75	1.00	5.58	43.43	56.57	1.40×10^7
Mottled Sculpin					6.99	1.65	1.26×10^7
Unidentifiable	100.00				86.00	14.00	8.95×10^6
All Species	4.68	14.56	21.43	6.43	30.20	20.32	1.51×10^5
							2.52×10^8

nearshore abundance entrained by power plants in the Central Basin in 1978. Examination of these values indicates a relatively small percentage of larvae of all species except white bass, johnny darter, freshwater drum and mottled sculpin were entrained. The relatively high entrainment estimates for white bass and freshwater drum can be explained using the estuary context developed in the preceding Western Basin discussion, i.e. preferred spawning habitat of these species was not sampled during this study.

Entrainment losses estimated from field collections were greatest at Ashtabula A & B Plant. An estimated 7.61×10^7 larvae representing 30.8% of the total were entrained here. Emerald shiner larvae were the most abundant larvae entrained at this plant (3.09×10^7 larvae, 41.79% of the total). Clupeid larvae were second (13.2% of the total). Yellow perch larvae represented 2.23% of the total entrainment at the Ashtabula A & B Plant. Field estimates indicated 21.43% of the total entrainment occurred at the Eastlake Plant and 20.32% at the Ashtabula C Plant. Estimated entrainment was lowest at the Lorain Edgewater Plant where 1.18×10^7 larvae were entrained. The latter represented 4.68% of the entrainment estimated at power plants located along the south shore of the Central Basin. The percentage of total entrainment at each power plant represented by each species is presented in Table 25.

In the Central Basin a species of major interest is yellow perch. Entrainment estimates based on field samples indicated yellow perch entrainment was highest at the Ashtabula A & B Plant where an estimated 7.61×10^7 larval yellow perch were entrained (30.80% of total yellow perch entrainment). The Ashtabula C Plant ranked second in yellow perch entrainment with 20.32% of the total. Calculated yellow perch entrainment was lowest at the Edgewater Plant where 1.18×10^7 (4.68% of the total) were entrained. A complete list of the percentage of the total entrainment estimate for each species entrained at each power plant is available in Table 26.

Entrainment estimates calculated using in-plant data (Table 17) indicate a total of 4.28×10^8 larvae were entrained by Central Basin power plants in 1978. Of these, 1.88×10^8 were cyprinids which comprised 54.7% of the total estimate. Carp larvae were the second most frequently entrained species (13.88% of the total). A total of 3.62×10^8 larval yellow perch, representing 1.11% of the total, ranked as the seventh most frequently entrained species (Table 27).

Comparison of entrainment estimates developed from in-plant samples with nearshore production estimates (Table 27) leads to the conclusion that a relatively small percentage of each fish species was entrained. Exceptions to this conclusion are the estimates for carp, white bass and log perch. It has been noted that our sampling program did not sample carp and white bass spawning habitat in estuarine areas. The inconsistency of the log perch estimate has no obvious explanation

TABLE 25. COMPARISON OF NEARSHORE PRODUCTION ESTIMATES AND TOTAL ENTRAINMENT ESTIMATES OF SIX CENTRAL BASIN POWER PLANTS DURING THE 1978 SAMPLING PERIOD (CALCULATED FROM FIELD SAMPLES)

Species	Nearshore Production	Entrainment Estimate	Percent Entrained
Clupeid	1.51×10^{10}	6.14×10^7	0.41
Rainbow Smelt	4.28×10^8	3.19×10^7	7.50
Carp/Goldfish	1.26×10^8	5.09×10^6	11.32
Emerald Shiner	4.28×10^9	8.01×10^7	1.87
Spottail Shiner	8.38×10^8	1.12×10^7	1.34
Burbot	2.58×10^6	1.49×10^5	5.78
Trout Perch	1.04×10^6	5.05×10^6	5.62
White Bass	1.92×10^6	9.43×10^5	49.08
Percidae	3.50×10^7	3.81×10^6	1.11
Walleye	5.69×10^6	1.17×10^5	2.10
Yellow Perch	1.09×10^8	4.60×10^6	4.23
Log Perch	5.23×10^7	5.07×10^6	9.69
Johnny Darter	1.12×10^8	1.40×10^7	12.50
Freshwater Drum	1.07×10^8	1.26×10^7	11.00
Mottled Sculpin	5.39×10^7	8.95×10^6	16.62

TABLE 26. TOTAL ENTRAINMENT AT CENTRAL BASIN POWER PLANTS (ESTIMATED FROM FIELD COLLECTIONS)

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)
Clupeid	67.03	64.85	17.06	29.44	13.20	10.94
Rainbow Smelt	2.47	3.46	40.56	5.76	5.86	5.98
Carp/Goldfish	4.05		0.72	16.67	1.79	0.26
Cyprinidae	0.35					
Emerald Shiner	8.20	2.02	24.63	14.75	41.79	60.42
Spottail Shiner	2.10	0.31	10.77	3.36	5.40	0.65
Burbot					0.10	0.14
Trout Perch			4.07	5.83	3.10	0.66
White Bass	7.99					
<u>Lepomis sp.</u>						0.01

TABLE 26 (continued). TOTAL ENTRAINMENT AT CENTRAL BASIN POWER PLANTS (ESTIMATED FROM FIELD COLLECTIONS)

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)
Percidae		0.38	0.12		4.18	0.83
Walleye			0.14	0.25		
Yellow Perch	0.41	0.27	1.59	6.79	2.23	1.55
Log Perch	2.25	0.69		12.72	3.07	0.29
Johnny Darter					7.99	15.47
Freshwater Drum	3.64	28.07	0.23	4.33	1.16	0.41
Mottled Sculpin					10.00	2.46
Unidentifiable	1.28					
Total	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 27. ESTIMATES OF THE RELATIVE ABUNDANCE OF FISH SPECIES ENTRAINED AT EACH OF SIX CENTRAL BASIN POWER PLANTS

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)	Total
Clupeid	15.95	68.43	4.84	3.86	6.30	0.56	3.68×10^7
Rainbow Smelt		79.88	15.48	1.80	0.24	2.54	3.23×10^7
White Sucker	3.74	41.03	45.49	5.59	3.65		2.04×10^6
Carp/Goldfish	0.61	20.20	35.18	11.70	32.30		4.52×10^7
Shiners	19.53	62.20	11.63	0.05	6.22	0.57	4.52×10^7
Minnows	7.98	23.79	30.28	2.42	35.40	0.16	2.09×10^8
Bluntnose Minnow		100.00					3.22×10^7
Burbot		100.00					2.42×10^5
Trout Perch	8.31	64.02	7.65	3.81	14.15	2.06	5.03×10^6

TABLE 27 (continued). ESTIMATES OF THE RELATIVE ABUNDANCE OF FISH SPECIES ENTRAINED AT EACH OF SIX CENTRAL BASIN POWER PLANTS

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)	Total
White Bass					100.0		2.00×10^5
Lepomis sp.	67.12	9.52				23.29	2.92×10^5
Micropterus sp.				100.00			1.70×10^5
Percidae			45.83		54.05		8.40×10^5
Sauger	100.0						2.09×10^4
Walleye					85.48	14.52	4.34×10^5
Yellow Perch		37.29	19.39		36.46	7.15	3.62×10^6
Freshwater Drum	27.36	56.94		15.83			7.20×10^5
Mottled Sculpin		72.58			27.42		2.99×10^5
Unidentifiable		49.49	35.70	2.88	10.08	1.86	4.93×10^7
All Species	11.82	54.44	18.53	2.55	11.85	0.89	4.28×10^8

except that problems in the study design as discussed in the section "Sources of Sample Variability" may be operating in this instance.

In-plant estimates of losses due to entrainment are greatest at the Avon Lake Plant where an estimated 2.33×10^6 (54.44% of the total) were entrained. Shiners were the most frequently entrained species (55.95% of Avon Lake total), followed by rainbow smelt (11.16%) and gizzard shad (10.87%). A total of 1.35×10^6 larval yellow perch (0.58%) were entrained at the Avon Lake Plant. The second highest entrainment estimates were calculated from in-plant collections at the Eastlake Plant where 7.93×10^7 larvae (18.53% of the total) were entrained. Entrainment at the Ashtabula A & B Plant and the Ohio Edison Edgewater Plant was essentially the same (5.06×10^7 and 5.07×10^7 larvae, respectively) with each contributing to 11.8% of the total Central Basin entrainment estimate. At the Ashtabula C Plant, an estimate of only 3.81×10^6 fish (0.89% of the total) were entrained. Table 28 gives the percentage of the total entrainment estimate for each species entrained at each plant.

Estimates indicated no larval yellow perch were entrained at either the Edgewater or Lake Shore Plants. Highest yellow perch entrainment was estimated at the Avon Lake Plant where 1.35×10^6 or 37.3% of the total yellow perch entrainment occurred. Entrainment at the Ashtabula A & B Plant was estimated at 1.32×10^6 yellow perch or 36.5% of the total perch entrainment. The Eastlake and Ashtabula C Plants accounted for the remaining 26.5% (19.7 and 7.1% respectively). The percentage of the total entrainment estimate for each species entrained at each power plant is presented in Table 29.

In general, the entrainment estimates derived from in-plant collections probably better represent the actual entrainment numbers than those calculated from field surveys. Not being weather-dependent, the in-plant collections were made on a more regular basis than field collections. Avoidance is less of a problem with pump-collected samples. One must use caution when comparing entrainment estimates derived from in-plant collections to abundance estimates derived from the field survey. The collection techniques are obviously different.

It should also be noted that the technique used in this study yields the number entrained, but does not thoroughly address the impact on adult populations. No mention has been made of mortality of entrained larvae, of natural mortality rates, or of density dependent mechanisms influencing natural mortality rates as influenced by entrainment. The state of the art in these areas is poorly developed at best.

In general, power plant entrainment of larval fishes probably has a rather small impact on Lake Erie fish populations, particularly in the Central Basin. In the Western Basin, losses due to entrainment of

species of commercial and/or sport interest are greatest at Toledo Edison's Bayshore Plant, due to its location at the mouth of the Maumee River estuary. Future power plants can be located to minimize losses due to entrainment. Power plants located in estuaries result in greater losses due to entrainment than those along the shoreline. The selection of an appropriate site along the shoreline must be made with care. The results of this study indicate selected areas along the Ohio shoreline contain valuable spawning and nursery areas for species of commercial and sport interest, i.e., the area between Little Cedar Point and Locust Point. Similarly the results of this study indicate the Detroit Edison Plant at Monroe is well located in a relatively depauperate area of the Western Basin. An alternative explanation, of course, is that the area is relatively devoid of larval fishes due to the operation of the plant.

TABLE 27. COMPARISON OF NEARSHORE PRODUCTION ESTIMATES AND TOTAL ENTRAINMENT ESTIMATES OF SIX CENTRAL BASIN POWER PLANTS DURING THE 1978 SAMPLING PERIOD (CALCULATED FROM IN-PLANT COLLECTIONS)

Species	Nearshore Production	Entrainment Estimate	Percent Entrained
Clupeid	1.51×10^{10}	3.68×10^7	0.24
Rainbow Smelt	4.28×10^8	3.23×10^7	7.51
White Sucker	1.65×10^6	2.04×10^6	124.00
Carp/Goldfish	1.26×10^8	4.52×10^7	35.92
Shiner & Minnow	5.22×10^9	2.41×10^8	4.61
Burbot	2.58×10^6	2.42×10^5	9.42
Trout Perch	1.04×10^8	5.03×10^6	4.84
White Bass	1.92×10^6	2.00×10^5	10.01
Percidae	3.50×10^7	8.40×10^5	2.42
Sauger	1.14×10^6	2.09×10^4	1.83
Walleye	5.69×10^6	4.34×10^5	7.61
Yellow Perch	1.09×10^8	3.62×10^6	3.32
Log Perch	5.23×10^7	8.15×10^6	15.01
Freshwater Drum	1.07×10^8	7.20×10^5	0.77
Mottled Sculpin	5.39×10^7	2.99×10^5	0.55

TABLE 28. PERCENTAGE OF TOTAL ESTIMATED ENTRAINMENT BY SPECIES AT EACH OF SIX CENTRAL BASIN POWER PLANTS

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)
Clupeid	55.42	10.87	2.24	13.07	4.58	5.49
Rainbow Smelt		11.16	6.29	5.46	0.15	21.92
White Sucker	0.01	0.36	1.17	1.05	0.15	
Carp/Goldfish	2.63	3.94	20.01	48.65	28.80	
Shiners	3.86	55.94	30.51	0.93	25.64	31.97
Minnows	24.26	3.31	12.26	7.16	22.48	1.30
Bluntnose Minnow	6.77					
Burbot		0.10				
Trout Perch	0.39	1.30	0.48	1.77	1.40	2.77
White Bass		0.09				

TABLE 28 (continued). PERCENTAGE OF TOTAL ESTIMATED ENTRAINMENT BY SPECIES AT EACH OF SIX CENTRAL BASIN POWER PLANTS

Species	Edgewater (%)	Avon Lake (%)	Eastlake (%)	Lake Shore (%)	Ashtabula A & B (%)	Ashtabula C (%)
<u>Lepomis</u> sp.	0.26		0.25		0.13	
Micropterus			0.48	1.56		
Percidae					1.01	
Sauger	0.20					1.70
Walleye					0.78	6.93
Yellow Perch		0.58	0.88		2.60	3.37
Log Perch	3.62	1.14	3.21	6.21	2.89	
Freshwater Drum	1.87	0.18		1.05		
Mottled Sculpin		0.09			0.16	
Unidentifiable		10.53	22.20	13.06	9.44	24.51
Total	100.00	100.00	100.00	100.00	100.00	100.00

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APPENDIX A

TABLE A-1. DEVELOPMENTAL STAGES AND RANGE OF LENGTHS OF LARVAL FISHES CAPTURED IN THE NEARSHORE ZONE AND THE MAUMEE AND SANDUSKY ESTUARIES OF THE WESTERN BASIN OF LAKE ERIE, 1975-1977

SPECIES	DEVELOPMENTAL STAGE ¹	MAUMEE AND SANDUSKY RIVER ESTUARIES-1975/1976 (mm)	NEARSHORE ZONE OF WESTERN BASIN 1977 (mm)
Gizzard Shad/Alewife	Pro-Larvae	3.0 - 6.5	
	Post-Larvae	4.0 - 18.0	5.0 - 25.0
Lake Whitefish	Post-Larvae		12.0 - 19.5
Rainbow Smelt	Post-Larvae		6.5 - 23.0
Carp/Goldfish	Pro-Larvae	4.5 - 7.0	4.5 - 6.0
	Post-Larvae	6.5 - 14.0	6.0 - 17.0
Emerald Shiner	Pro-Larvae	4.7 - 6.0	
	Post-Larvae	5.0 - 15.0	6.0 - 14.0
Spottail Shiner	Pro-Larvae		5.0 - 6.0
	Post-Larvae		6.0 - 17.0
Quillback	Pro-Larvae		8.5 - 12.0
	Post-Larvae		12.0 - 13.0
White Sucker	Pro-Larvae	6.8 - 8.0	
	Post-Larvae	8.0 - 17.0	12.5 - 21.0
Channel Catfish	Post-Larvae		13.0 - 17.0
Trout Perch	Pro-Larvae	6.0 - 7.0	5.0 - 7.0
	Post-Larvae	7.0 - 10.0	
White Bass/White Perch	Pro-Larvae	2.5 - 3.5	4.0 - 7.0
	Post-Larvae	3.5 - 14.0	7.0 - 20.0
Sunfish	Pro-Larvae	4.0 - 5.5	6.0
	Post-Larvae	5.5 - 9.0	7.0 - 10.0
Crappie	Pro-Larvae	2.5 - 5.0	
	Post-Larvae	4.0 - 16.0	7.0 - 8.0
Yellow Perch	Pro-Larvae	4.1 - 7.0	4.0 - 6.0
	Post-Larvae	7.0 - 13.0	6.0 - 21.0
Sauger	Pro-Larvae		6.5 - 8.5
	Post-Larvae		9.0
Walleye	Pro-Larvae	6.0 - 10.0	6.0 - 9.0
	Post-Larvae	9.5 - 15.0	9.0 - 22.0
Logperch	Pro-Larvae	4.5 - 6.2	6.0
	Post-Larvae	5.5 - 14.0	6.5 - 21.0
Freshwater Drum	Pro-Larvae	2.0 - 4.4	4.0 - 6.5
	Post-Larvae	4.4 - 15.0	7.0 - 15.0

¹Developmental stages as defined by Hubbs (1944)

APPENDIX A

TABLE A-2. DEVELOPMENTAL STAGES¹ AND RANGE OF LENGTHS OF SELECTED LARVAL FISH CAPTURED IN THE WESTERN BASIN DURING 1975 AND 1976

SPECIES	DEVELOPMENTAL STAGE	RANGE (mm)
Gizzard Shad/Alewife	Protolarvae	3.0 - 10.0
	Mesolarvae	9.0 - 15.0
	Metalarvae	15.0 - 20.0
	Juveniles	22+
Emerald Shiner	Protolarvae	4.0 - 8.0
	Mesolarvae	8.0 - 10.0
	Metalarvae	11.0 - 14.0
	Juveniles	13.0+
White Bass/White Perch	Protolarvae	3.0 - 8.0
	Mesolarvae	8.0 - 11.0
	Metalarvae	10.0 - 23.0
Yellow Perch	Protolarvae	4.0 - 10.0
	Mesolarvae	10.0 - 13.0
	Metalarvae	13.0 - 17.0
Freshwater Drum	Protolarvae	3.0 - 5.5
	Mesolarvae	6.0 - 7.0

¹Developmental stages as defined by Snyder (1977).

TABLE A-3. DEVELOPMENTAL STAGES ¹ AND RANGE OF LENGTHS OF
SELECTED LARVAL FISHES CAPTURED IN THE NEARSHORE
ZONE OF WESTERN LAKE ERIE DURING 1977

SPECIES	DEVELOPMENTAL STAGE	RANGE (mm)
Gizzard Shad/Alewife	Protolarvae	4.0 - 10.0
	Mesolarvae	10.0 - 16.0
	Metalarvae	14.0 - 22.0
White Bass/White Perch	Protolarvae	4.0 - 8.0
	Mesolarvae	8.0 - 12.0
	Metalarvae	10.0 - 20.0
Walleye	Protolarvae	6.0 - 11.0
Logperch	Protolarvae	5.0 - 8.0
	Mesolarvae	11.0 - 15.0
	Metalarvae	15.0 - 21.0
Freshwater Drum	Protolarvae	5.0 - 6.0
	Mesolarvae	7.0 - 13.0
	Metalarvae	9.0 - 22.0

¹Developmental stages as defined by Snyder (1977).

APPENDIX B

TABLE B-1. VOLUME WEIGHTED ESTIMATES OF LARVAL ABUNDANCE IN THREE NEARSHORE DEPTH ZONES OF THE WESTERN BASIN (1977)

SPECIES	0-1 Meter Depth Zone	1-3 Meter Depth Zone	3-5 Meter Depth Zone	Western Basin Nearshore Total
Gizzard Shad	3.12 x 10 ⁹ 3.91 x 10 ⁸	2.64 x 10 ⁹ 2.83 x 10 ⁹	4.52 x 10 ⁹ 3.96 x 10 ⁸	1.03 x 10 ¹⁰ 4.62 x 10 ⁸
Whitefish	4.99 x 10 ⁴ 1.73 x 10 ⁵	4.80 x 10 ⁵ 1.78 x 10 ⁵	7.47 x 10 ⁵ 2.11 x 10 ⁵	2.32 x 10 ⁶ 4.71 x 10 ⁵
Rainbow Smelt	1.89 x 10 ⁶ 2.21 x 10 ⁷	1.63 x 10 ⁷ 2.26 x 10 ⁶	2.81 x 10 ⁷ 3.51 x 10 ⁶	6.34 x 10 ⁷ 2.92 x 10 ⁶
Quillback Carp sucker	2.13 x 10 ⁵ 1.06 x 10 ⁵	3.08 x 10 ⁵ 1.16 x 10 ⁵	2.44 x 10 ⁵ 7.13 x 10 ⁴	7.65 x 10 ⁵ 2.28 x 10 ⁴
White Sucker	4.99 x 10 ⁴ 1.73 x 10 ⁴	4.80 x 10 ⁵ 1.78 x 10 ⁵	7.47 x 10 ⁵ 2.11 x 10 ⁵	1.28 x 10 ⁶ 1.66 x 10 ⁵
Carp	8.76 x 10 ⁶ 7.22 x 10 ⁵	3.59 x 10 ⁷ 3.02 x 10 ⁶	1.20 x 10 ⁸ 1.67 x 10 ⁷	1.64 x 10 ⁸ 2.73 x 10 ⁷

TABLE B-1 (continued).

SPECIES	0-1 Meter Depth Zone	1-3 Meter Depth Zone	3-5 Meter Depth Zone	Western Basin Nearshore Total
Cyprinidae	2.42 x 10 ⁵ 8.89 x 10 ⁴	3.51 x 10 ⁵ 4.21 x 10 ⁴	7.70 x 10 ⁴	6.70 x 10 ⁵ 6.50 x 10 ⁴
Emerald Shiner	5.58 x 10 ⁷ 6.75 x 10 ⁶	1.81 x 10 ⁸ 3.62 x 10 ⁷	2.78 x 10 ⁸ 5.24 x 10 ⁷	5.16 x 10 ⁸ 5.22 x 10 ⁷
Spottail Shiner	2.01 x 10 ⁶ 2.87 x 10 ⁵	5.10 x 10 ⁶ 9.27 x 10 ⁵	5.59 x 10 ⁶ 1.11 x 10 ⁶	1.27 x 10 ⁷ 9.16 x 10 ⁵
Channel Catfish	3.13 x 10 ⁵ 1.04 x 10 ⁵	9.38 x 10 ⁴ 8.01 x 10 ³	2.62 x 10 ⁵ 2.24 x 10 ⁴	6.69 x 10 ⁵ 5.41 x 10 ⁴
Trout Perch	1.22 x 10 ⁴ 2.10 x 10 ³	1.45 x 10 ⁵ 2.20 x 10 ⁴	2.27 x 10 ⁵ 7.55 x 10 ⁴	3.83 x 10 ⁵ 5.10 x 10 ⁴
White Bass	1.31 x 10 ⁸ 1.55 x 10 ⁷	5.21 x 10 ⁷ 4.86 x 10 ⁶	8.26 x 10 ⁷ 1.04 x 10 ⁷	2.65 x 10 ⁸ 1.87 x 10 ⁷
<u>Pomoxis</u> sp.		3.41 x 10 ⁵	1.29 x 10 ⁶	1.63 x 10 ⁶ 3.16 x 10 ⁵

TABLE B-1 (continued).

SPECIES	0-1 Meter Depth Zone	1-3 Meter Depth Zone	3-5 Meter Depth Zone	Western Basin Nearshore Total
<u>Lepomis</u> sp.	2.21 x 10 ⁵ 9.95 x 10 ⁴	2.52 x 10 ⁵ 1.12 x 10 ⁵	6.43 x 10 ⁵ 1.53 x 10 ⁵	4.12 x 10 ⁶ 1.11 x 10 ⁵
Percidae	2.66 x 10 ⁵			2.66 x 10 ⁵ 7.24 x 10 ⁴
Sauger	7.56 x 10 ⁵	1.49 x 10 ⁶		2.25 x 10 ⁶ 2.59 x 10 ⁵
Walleye	4.63 x 10 ⁶ 4.12 x 10 ⁵	2.27 x 10 ⁷ 2.12 x 10 ⁶	3.35 x 10 ⁷ 4.14 x 10 ⁶	6.08 x 10 ⁷ 6.87 x 10 ⁶
Yellow Perch	1.41 x 10 ⁸ 1.23 x 10 ⁷	4.46 x 10 ⁸ 3.85 x 10 ⁷	7.58 x 10 ⁸ 6.99 x 10 ⁷	1.35 x 10 ⁹ 1.46 x 10 ⁸
Log Perch	6.65 x 10 ⁶ 7.44 x 10 ⁵	2.95 x 10 ⁷ 3.77 x 10 ⁶	3.20 x 10 ⁷ 2.51 x 10 ⁶	6.82 x 10 ⁷ 6.59 x 10 ⁶

TABLE B-1 (continued).

SPECIES	0-1 Meter Depth Zone	1-3 Meter Depth Zone	3-5 Meter Depth Zone	Western Basin Nearshore Total
Freshwater Drum	2.52 x 10 ⁷ 4.11 x 10 ⁶	9.41 x 10 ⁷ 1.64 x 10 ⁷	2.24 x 10 ⁷ 1.93 x 10 ⁸	1.42 x 10 ⁸ 1.91 x 10 ⁷
Unidentifiable	1.03 x 10 ⁶ 4.48 x 10 ⁴	3.33 x 10 ⁵		1.36 x 10 ⁶ 2.48 x 10 ⁵
Total	3.52 x 10 ⁹ 2.04 x 10 ⁸	3.53 x 10 ⁹ 1.23 x 10 ⁸	5.88 x 10 ⁹ 2.06 x 10 ⁸	1.30 x 10 ¹⁰ 4.77 x 10 ⁸

APPENDIX B

TABLE B-2. VOLUME WEIGHTED ESTIMATES (FOR ENTIRE SAMPLING PERIOD) OF LARVAL FISHES IN THE NEARSHORE ZONE OF THE CENTRAL BASIN IN 1978

SPECIES	0-1 METER DEPTH ZONE	3-5 METERS DEPTH ZONE	5-10 METERS DEPTH ZONE	CENTRAL BASIN NEARSHORE TOTAL
Gizzard Shad	1.09 x 10 ⁶ 9.05 x 10 ⁴	5.06 x 10 ⁸ 3.85 x 10 ⁷	1.00 x 10 ¹⁰ 7.36 x 10 ⁸	1.51 x 10 ¹⁰ 2.88 x 10 ⁹
Rainbow Smelt	8.30 x 10 ⁴ 1.02 x 10 ⁴	7.48 x 10 ⁷ 6.38 x 10 ⁶	3.53 x 10 ⁸ 2.56 x 10 ⁷	4.28 x 10 ⁸ 1.07 x 10 ⁸
Quillback Carpsucker	1.32 x 10 ³ 7.20 x 10 ²	5.54 x 10 ⁵ 3.97 x 10 ⁴		5.55 x 10 ⁵ 1.84 x 10 ⁵
White Sucker	2.74 x 10 ³ 1.93 x 10 ³	1.34 x 10 ⁶ 1.09 x 10 ⁵	3.12 x 10 ⁵ 7.11 x 10 ⁴	1.65 x 10 ⁶ 4.03 x 10 ⁵
Carp	2.47 x 10 ⁵ 2.17 x 10 ⁴	1.09 x 10 ⁸ 8.51 x 10 ⁶	2.53 x 10 ⁷ 2.18 x 10 ⁶	1.26 x 10 ⁸ 3.00 x 10 ⁷
Cyprinidae sp.	1.80 x 10 ⁵ 2.10 x 10 ⁴	8.00 x 10 ⁷ 9.01 x 10 ⁶	1.73 x 10 ⁷ 1.49 x 10 ⁶	9.75 x 10 ⁷ 2.43 x 10 ⁷
Golden Shiner	1.49 x 10 ² 7.40 x 10	2.24 x 10 ⁵ 3.85 x 10 ⁴	4.27 x 10 ⁴ 4.20 x 10 ³	2.67 x 10 ⁵ 6.18 x 10 ⁴

TABLE B-2. (continued)

SPECIES	0-1 METER DEPTH ZONE	3-5 METERS DEPTH ZONE	5-10 METERS DEPTH ZONE	CENTRAL BASIN NEARSHORE TOTAL
Striped Shiner	7.14 x 10 ³ 7.14 x 10 ²	4.00 x 10 ⁶ 1.22 x 10 ⁶	3.64 x 10 ⁶ 1.04 x 10 ⁶	7.65 x 10 ⁶ 1.28 x 10 ⁶
Emerald Shiner	4.83 x 10 ⁵ 6.51 x 10 ⁴	7.43 x 10 ⁸ 1.09 x 10 ⁸	3.53 x 10 ⁹ 6.80 x 10 ⁸	4.28 x 10 ⁹ 1.08 x 10 ⁹
Spottail Shiner	1.77 x 10 ⁶ 1.93 x 10 ⁵	7.26 x 10 ⁸ 8.18 x 10 ⁷	1.04 x 10 ⁸ 4.43 x 10 ⁷	8.38 x 10 ⁸ 2.26 x 10 ⁷
Burbot	3.26 x 10 ³ 3.40 x 10 ²	1.80 x 10 ⁶ 9.58 x 10 ⁵	7.86 x 10 ⁵ 7.86 x 10 ⁴	2.58 x 10 ⁶ 5.19 x 10 ⁵
Trout Perch	1.07 x 10 ⁵ 6.51 x 10 ³	6.00 x 10 ⁷ 3.64 x 10 ⁶	4.42 x 10 ⁷ 2.20 x 10 ⁶	1.04 x 10 ⁸ 1.79 x 10 ⁷
White Bass	1.74 x 10 ³ 1.93 x 10 ²	2.31 x 10 ⁵ 6.36 x 10 ⁴	1.69 x 10 ⁶ 6.79 x 10 ⁵	1.92 x 10 ⁶ 5.28 x 10 ⁵
<u>Pomoxis</u> sp.	6.41 x 10 ² 1.42 x 10 ²	3.24 x 10 ⁵ 4.81 x 10 ⁴	1.11 x 10 ⁶ 2.25 x 10 ⁵	1.43 x 10 ⁶ 3.28 x 10 ⁵

TABLE B-2. (continued)

SPECIES	0-1 METER DEPTH ZONE	3-5 METERS DEPTH ZONE	5-10 METERS DEPTH ZONE	CENTRAL BASIN NEARSHORE TOTAL
Black Crappie	1.86 x 10 ² 1.86 x 10 ²	9.35 x 10 ⁴ 9.35 x 10 ⁴	2.15 x 10 ⁷ 3.15 x 10 ⁶	2.16 x 10 ⁷ 7.14 x 10 ⁶
<u>Lepomis</u> sp.	1.46 x 10 ³ 2.98 x 10 ²	1.22 x 10 ⁶ 1.52 x 10 ⁵	6.72 x 10 ⁵ 1.12 x 10 ⁵	1.89 x 10 ⁶ 3.52 x 10 ⁵
Percidae sp.	7.13 x 10 ³ 1.56 x 10 ²	1.35 x 10 ⁷ 1.64 x 10 ⁶	2.15 x 10 ⁷ 3.15 x 10 ⁶	3.50 x 10 ⁷ 6.27 x 10 ⁶
Sauger	2.16 x 10 ³ 2.16 x 10 ³	1.14 x 10 ⁶ 1.28 x 10 ⁵		1.14 x 10 ⁶ 3.80 x 10 ⁵
Walleye	2.39 x 10 ³ 3.14 x 10 ²	2.55 x 10 ⁶ 3.47 x 10 ⁵	3.14 x 10 ⁶ 6.69 x 10 ⁵	5.69 x 10 ⁶ 9.63 x 10 ⁵
Yellow Perch	1.24 x 10 ⁵ 1.15 x 10 ⁴	6.50 x 10 ⁶ 5.84 x 10 ⁵	4.40 x 10 ⁷ 3.50 x 10 ⁶	1.09 x 10 ⁸ 1.91 x 10 ⁷

APPENDIX C

TABLE C-1. Determination of the Average Lifetime Fecundity (F_a) of a Three Year-Old Recruit to the Yellow Perch Population of the Ohio Waters of the Western Basin of Lake Erie.

AGE	S_j ¹	P_j ²	E_j ³	$P_j S_j E_j$ ⁴
2	1.00	0.14	---	---
3	0.94	0.85	15,000	13564
4	0.62	0.95	17,500	10308
5	0.06	1.00	20,000	1200
6	0.001	1.00	20,000	<u>20</u>

$$F_a = \sum_{j=3}^6 P_j S_j E_j = 25092$$

¹From Davies, D. H., M. R. Rawson and G. A. Emond. 1979. Performance Report. Lake Erie Fishery Research, Fed. Aid Proj. F-35-R-17, Study II. 56 p.

²Preliminary data from M. R. Rawson. Pers. comm.

³Van Meter, H. 1966. Yellow Perch Fecundity. Unpublished memo.

⁴The survival fraction (S_j) of females and the fraction of mature females within each age class (P_j) and the fecundity of mature females within each age class (E_j) are estimated from published and unpublished sources.

APPENDIX C

TABLE C-2. Seasonal Length Frequency Distribution of Larval Yellow Perch Needed to Estimate the Instantaneous Rate of Mortality on Length (d).

LENGTH CLASS (l)	LENGTH (mm)	NUMBER COLLECTED	
		(1975)	(1976)
1	6.0- 6.9	833	836
2	7.0- 7.9	389	160
3	8.0- 8.9	220	68
4	9.0- 9.9	212	41
5	10.0-10.9	234	60
6	11.0-11.9	36	37
7	12.0-12.9	11	22
8	13.0-13.9	8	12
9	14.0-14.9	7	3

$$d = -\ln \frac{\sum_{l=2}^9 N_l}{\sum_{l=1}^9 N_l}$$

$$d_{1975} = 0.5568$$

$$d_{1976} = 1.1231$$

APPENDIX C

TABLE C-3. Estimates of S_{e^1} and S_j , for Each Length Class of Larval Yellow Perch.¹

LENGTH CLASS	LENGTH (mm)	SURVIVAL PROBABILITY FROM EGG TO LENGTH CLASS / (S_{e^1}) ³		SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 3	
		1975	1976	1975	1976
1	6.0- 6.9	0.0749	0.0752	0.0016	0.0016
2	7.0- 7.9	0.0350	0.0144	0.0034	0.0083
3	8.0- 8.9	0.0199	0.0061	0.0060	0.0196
4	9.0- 9.9	0.0191	0.0037	0.0063	0.0323
5	10.0-10.9	0.0211	0.0054	0.0057	0.0221
6	11.0-11.9	0.0032	0.0033	0.0374	0.0362
7	12.0-12.9	0.0010	0.0020	0.1196	0.0598
8	13.0-13.9	0.0007	0.0011	0.1708	0.1087
9	14.0-14.9	0.0006	0.0003	0.1993	0.3984

$$S_{e^1} = H \frac{N_e}{N_o}$$

$$S_j = \frac{3}{S_{e^1} F_u}$$

H = fraction of eggs that hatch
 Ne = number of larvae of length class /
 No = estimated initial number of larvae

¹Parameter estimates are 0.135, ² $d_{1975} = 0.5568$, $d_{1976} = 1.1231$, $F_u = 25092$ and $h = 4$ mm

²Estimated by averaging fractions of eggs that hatch on various substrates reported by Johnson (1961) for walleye (*Stizostedion v. vitreum*) in Lake Winnibogoshigh, Minnesota.

³Note that length at hatching (h) is 4 mm which is 2 mm less than the first length class for which data are available. In performing the calculations of S_{e^1} , the value of d was assumed to be correct for these smaller length classes.

APPENDIX C

TABLE C-4. Estimate of the Loss of Three Year-Old Yellow Perch Recruits as a Result of Entrainment Mortality at the Davis-Besse Nuclear Power Plant in 1976.¹

LENGTH CLASS (")	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED 1.00	NUMBER OF LARVAE OF LENGTH CLASS / N _i	SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 3 S _i	ADULTS (AGE 3)	
							PER DAY	PERIOD OF CAPTURE
1	6.0- 6.9	0.065	8x10 ⁴	1.00	5200	0.0016	8.32	216.3
2	7.0- 7.9	0.012	8x10 ⁴	1.00	960	0.0083	7.97	207.2
3	8.0- 8.9	0.003	8x10 ⁴	1.00	240	0.0196	4.70	150.5
4	9.0- 9.9	0.001	8x10 ⁴	1.00	80	0.0323	2.58	82.7
5	10.0-10.9	0.002	8x10 ⁴	1.00	160	0.0221	3.54	148.5
6	11.0-11.9	0.001	8x10 ⁴	1.00	80	0.0362	2.90	57.9
7	12.0-12.9	0.0007	8x10 ⁴	1.00	56	0.0598	3.35	67.0
8	13.0-13.9	0.0006	8x10 ⁴	1.00	48	0.1087	5.22	15.7
9	14.0-14.9	0.00003	8x10 ⁴	1.00	2.4	0.3984	0.96	2.9
TOTAL				1.00			39.54	948.7

¹Davis-Besse did not operate during 1975

APPENDIX C

TABLE C-5. Estimate of the Loss of Three Year Old Yellow Perch Recruits as a Result of Entrainment Mortality at the Bayshore Power Plant in 1975.

LENGTH CLASS (")	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED	NUMBER OF LARVAE OF LENGTH CLASS / N _i	SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 3 S _i	ADULTS (AGE 3)	
							NO./DAY	PERIOD OF CAPTURE
1	6.0- 6.9	0.081	2.8x10 ⁶	$\frac{1.00}{0.66}$	2.268x10 ⁵	0.0016	$\frac{362.88}{239.50}$	$\frac{13063.7}{8622.0}$
2	7.0- 7.9	0.038	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.064x10 ⁵	0.0034	$\frac{361.75}{238.76}$	$\frac{13023.4}{8595.4}$
3	8.0- 8.9	0.024	2.8x10 ⁶	$\frac{1.00}{0.66}$	6.72x10 ⁴	0.0060	$\frac{403.20}{266.11}$	$\frac{14515.2}{9580.0}$
4	9.0- 9.9	0.023	2.8x10 ⁶	$\frac{1.00}{0.66}$	6.44x10 ⁴	0.0063	$\frac{405.72}{267.78}$	$\frac{14605.9}{9639.9}$
5	10.0-10.9	0.021	2.8x10 ⁶	$\frac{1.00}{0.66}$	5.88x10 ⁴	0.0057	$\frac{335.16}{221.21}$	$\frac{12065.8}{7963.4}$
6	11.0-11.9	0.004	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.12x10 ⁴	0.0374	$\frac{418.88}{276.46}$	$\frac{15079.7}{9952.6}$
7	12.0-12.9	0.0036	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.008x10 ⁴	0.1196	$\frac{1205.57}{795.67}$	$\frac{32550.3}{21483.2}$
8	13.0-13.9	0.003	2.8x10 ⁶	$\frac{1.00}{0.66}$	8.4x10 ³	0.1708	$\frac{1434.72}{946.92}$	$\frac{38737.4}{25566.7}$
9	14.0-14.9	0.002	2.8x10 ⁶	$\frac{1.00}{0.66}$	5.6x10 ³	0.1993	$\frac{1116.08}{736.61}$	$\frac{39062.8}{25781.4}$
TOTAL				$\frac{1.00}{0.66}$			$\frac{6043.96}{3989.01}$	$\frac{192704.2}{127184.8}$

APPENDIX C

TABLE C-6. Estimate of the Loss of Three Year-old Yellow Perch Recruits as a Result of Entrainment Mortality at the Bayshore Power Plant in 1976.

LENGTH CLASS (l)	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED	NUMBER OF LARVAE OF LENGTH CLASS / N _l	SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 3 S _l	ADULTS (AGE 3)	
							NO./DAY	PERIOD OF CAPTURE
1	6.0- 6.9	0.065	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.82x10 ⁵	0.0016	$\frac{291.20}{192.19}$	$\frac{7571.2}{4997.0}$
2	7.0- 7.9	0.012	2.8x10 ⁶	$\frac{1.00}{0.66}$	3.36x10 ⁴	0.0083	$\frac{278.88}{184.06}$	$\frac{7250.9}{4785.6}$
3	8.0- 8.9	0.003	2.8x10 ⁶	$\frac{1.00}{0.66}$	8.40x10 ³	0.0196	$\frac{164.64}{108.66}$	$\frac{5268.5}{3477.2}$
4	9.0- 9.9	0.001	2.8x10 ⁶	$\frac{1.00}{0.66}$	2.80x10 ³	0.0323	$\frac{90.44}{59.69}$	$\frac{2894.1}{1910.1}$
5	10.0-10.9	0.002	2.8x10 ⁶	$\frac{1.00}{0.66}$	5.60x10 ³	0.0221	$\frac{123.76}{81.68}$	$\frac{5197.9}{3430.6}$
6	11.0-11.9	0.001	2.8x10 ⁶	$\frac{1.00}{0.66}$	2.80x10 ³	0.0362	$\frac{101.36}{66.90}$	$\frac{2027.2}{1337.9}$
7	12.0-12.9	0.0007	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.96x10 ³	0.0598	$\frac{117.20}{77.40}$	$\frac{2344.2}{1547.1}$
8	13.0-13.9	0.0006	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.68x10 ³	0.1087	$\frac{182.62}{120.53}$	$\frac{3652.3}{2410.5}$
9	14.0-14.9	0.00003	2.8x10 ⁶	$\frac{1.00}{0.66}$	8.40x10 ²	0.3984	$\frac{33.50}{22.09}$	$\frac{100.4}{66.3}$
TOTAL				$\frac{1.00}{0.66}$			$\frac{1383.6}{913.18}$	$\frac{36306.7}{23962.4}$

APPENDIX C

TABLE C-7. ESTIMATE OF THE LOSS OF THREE-YEAR-OLD YELLOW PERCH RECRUITS AS A RESULT OF ENTRAINMENT MORTALITY AT THE BAYSHORE POWER PLANT IN 1977.

LENGTH CLASS (L)	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED	NUMBER OF LARVAE OF LENGTH CLASS L N _L	SURVIVAL PROBABILITY FROM LENGTH CLASS L TO AGE 3 S _L	ADULTS (AGE 3)	
							NO./DAY	PERIOD OF CAPTURE (33 DAYS)
1	6.0-6.9	.3117	2.8x10 ⁶	$\frac{1.00}{0.66}$	8.7276x10 ⁵	0.0016	$\frac{1.4x10^3}{9.2x10^2}$	$\frac{4.6x10^4}{3.0x10^4}$
2	7.0-7.9	.3158	2.8x10 ⁶	$\frac{1.00}{0.66}$	8.8424x10 ⁵	0.0083	$\frac{7.3x10^3}{4.8x10^3}$	$\frac{2.4x10^5}{1.6x10^5}$
3	8.0-8.9	.1646	2.8x10 ⁶	$\frac{1.00}{0.66}$	4.6088x10 ⁵	0.0196	$\frac{9.0x10^3}{6.0x10^3}$	$\frac{3.0x10^5}{2.0x10^5}$
4	9.0-9.9	.0647	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.8116x10 ⁵	0.0323	$\frac{5.9x10^3}{3.9x10^3}$	$\frac{1.9x10^5}{1.3x10^5}$
5	10.0-10.9	.0399	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.1172x10 ⁵	0.0221	$\frac{2.5x10^3}{1.6x10^3}$	$\frac{8.1x10^4}{5.4x10^4}$
6	11.0-11.9	.0564	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.5792x10 ⁵	0.0362	$\frac{5.7x10^3}{3.8x10^3}$	$\frac{1.9x10^5}{1.2x10^5}$
7	12.0-12.9	.0582	2.8x10 ⁶	$\frac{1.00}{0.66}$	1.6296x10 ⁵	0.0598	$\frac{9.7x10^3}{6.4x10^3}$	$\frac{3.2x10^5}{2.1x10^5}$
8	13.0-13.9	.0789	2.8x10 ⁶	$\frac{1.00}{0.66}$	2.2092x10 ⁵	0.1087	$\frac{2.4x10^4}{1.5x10^4}$	$\frac{7.9x10^5}{5.2x10^5}$
							$\frac{6.5x10^4}{4.3x10^4}$	$\frac{2.2x10^6}{1.4x10^6}$

APPENDIX D

TABLE D-1. Determination of the Average Lifetime Fecundity (F_a) of a One Year-old Recruit to the Western Basin Emerald Shiner Population.¹

AGE	S_j	P_j	E_j	$P_j S_j E_j$
0	1.00	0.00	---	0
1	0.655	0.296	1800	349
2	0.345	0.561	4000	774
3	0.170	0.092	8000	125
4	0.019	0.051	8000	8

$$F_a = \sum_{j=0}^4 P_j S_j E_j = 1256$$

¹The survival fraction (S_j) of females, the fraction (P_j) of females within each age class and the fecundity of mature females (E_j) are known (Flittner, 1964).

APPENDIX D

TABLE D-2. Seasonal Length Frequency Distribution of Emerald Shiner Larvae Needed to Estimate the Instantaneous Rate of Mortality on Length (d).

LENGTH CLASS (l)	LENGTH (mm)	NUMBER COLLECTED	
		1975	1976
1	7.0- 7.9	340	---
2	8.0- 8.9	167	---
3	9.0- 9.9	176	1054
4	10.0-10.9	114	475
5	11.0-11.9	45	367
6	12.0-12.9	22	245
7	13.0-13.9	12	97
8	14.0-14.9	6	5
9	15.0-15.9	2	1

$$d_{1975} = -1n \frac{\sum_{l=2}^9 N_l}{9} = -1n 0.61538 = 0.4855$$

$$d_{1976} = -1n 0.53030 = 0.6343$$

APPENDIX D

TABLE D-3. Estimates of $S_{e,l}$ and S_l for Each Length Class of Larval Emerald Shiner.¹

LENGTH CLASS	LENGTH (mm)	SURVIVAL PROBABILITY FROM EGG TO LENGTH CLASS / ($S_{e,l}$) ²		SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 1	
		1975	1976	1975	1976
1	7.0- 7.9	0.0531	---	0.0199	---
2	8.0- 8.9	0.0261	---	0.0305	---
3	9.0- 9.9	0.0275	0.1647	0.0289	0.0048
4	10.0-10.9	0.0178	0.0742	0.0447	0.0107
5	11.0-11.9	0.0070	0.0573	0.1137	0.0139
6	12.0-12.9	0.0034	0.0383	0.2342	0.0208
7	13.0-13.9	0.0019	0.0152	0.4191	0.0524
8	14.0-14.9	0.0009	0.0008	0.8849	0.9950
9	15.0-15.9	0.0003	0.0002	2.6539	3.9891

$$S_{e,l} = H \frac{N_e}{N_0}$$

$$S_l = \frac{1}{S_{e,l} F_d}$$

H = fraction of eggs that hatch
 N_e = number of larvae of length class
 N₀ = estimated initial number of larvae

¹Parameter estimates are 0.25, $d_{1975} = 0.486$, $d_{1976} = 0.634$, $F_d = 1256$ and $h = 5$ mm

²Note that length at hatching (h) is 5 mm which is 2-4 mm less than the first length class for which adequate data are available. In performing the calculations of $S_{e,l}$, the value of d was assumed to be correct for these smaller length classes.

APPENDIX D

TABLE D-4. Estimate of the Loss of One Year-old Emerald Shiner Recruits as a Result of Entrainment Mortality at the Toledo Edison Bayshore Power Plant in 1975.

LENGTH CLASS (/)	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED	NUMBER OF LARVAE OF LENGTH CLASS / N _i	SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 1	ADULTS (AGE 1)	
							PER DAY	PERIOD OF CAPTURE
1	7.0- 7.9	0.0333	2.8x10 ⁶	$\frac{1.00}{0.66}$	93,240	0.0199	$\frac{1,855.48}{1,224.61}$	$\frac{179,981.2}{118,787.6}$
2	8.0- 8.9	0.0111	2.8x10 ⁶	$\frac{1.00}{0.66}$	31,080	0.0305	$\frac{947.94}{625.64}$	$\frac{91,950.2}{60,687.1}$
3	9.0- 9.9	0.0097	2.8x10 ⁶	$\frac{1.00}{0.66}$	27,160	0.0289	$\frac{784.92}{518.05}$	$\frac{65,148.7}{42,998.1}$
4	10.0-10.9	0.0068	2.8x10 ⁶	$\frac{1.00}{0.66}$	19,040	0.0447	$\frac{851.09}{561.72}$	$\frac{70,640.3}{46,622.6}$
5	11.0-11.9	0.0028	2.8x10 ⁶	$\frac{1.00}{0.66}$	7,840	0.1137	$\frac{891.41}{588.33}$	$\frac{57,941.5}{38,241.4}$
6	12.0-12.9	0.0022	2.8x10 ⁶	$\frac{1.00}{0.66}$	6,160	0.2342	$\frac{1,442.67}{952.16}$	$\frac{93,773.7}{61,890.6}$
7	13.0-13.9	0.0011	2.8x10 ⁶	$\frac{1.00}{0.66}$	3,080	0.4191	$\frac{1,290.83}{851.95}$	$\frac{83,903.8}{55,376.5}$
8	14.0-14.9	0.0005	2.8x10 ⁶	$\frac{1.00}{0.66}$	1,400	0.8849	$\frac{1,238.86}{817.65}$	$\frac{80,525.9}{53,147.1}$
9	15.0-15.9	0.0002	2.8x10 ⁶	$\frac{1.00}{0.66}$	560	2.6539	$\frac{1,486.18}{980.88}$	$\frac{14,861.8}{9,808.8}$
TOTAL				$\frac{1.00}{0.66}$			$\frac{10,789.38}{7,120.99}$	$\frac{738,727.1}{487,560.3}$

APPENDIX D

TABLE D-5. Estimate of the Loss of One Year-old Emerald Shiner Recruits as a Result of Entrainment Mortality at the Toledo Edison Bayshore Power Plant in 1976.

LENGTH CLASS (/)	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED	NUMBER OF LARVAE OF LENGTH CLASS / N _i	SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 1 S _i	ADULTS (AGE 1)	
							PER DAY	PERIOD OF CAPTURE
1	9.0- 9.9	0.320	2.8x10 ⁶	$\frac{1.00}{0.66}$	896,000	0.0048	$\frac{4,300.80}{2,838.53}$	$\frac{206,438.4}{136,249.3}$
2	10.0-10.9	0.166	2.8x10 ⁶	$\frac{1.00}{0.66}$	464,800	0.0107	$\frac{4,973.36}{3,282.41}$	$\frac{238,721.3}{157,556.0}$
3	11.0-11.9	0.131	2.8x10 ⁶	$\frac{1.00}{0.66}$	366,800	0.0139	$\frac{5,098.52}{3,366.02}$	$\frac{244,729.0}{161,521.1}$
4	12.0-12.9	0.072	2.8x10 ⁶	$\frac{1.00}{0.66}$	201,600	0.0208	$\frac{4,193.28}{2,767.56}$	$\frac{201,277.4}{132,843.1}$
5	13.0-13.9	0.029	2.8x10 ⁶	$\frac{1.00}{0.66}$	81,200	0.0524	$\frac{4,254.86}{2,808.22}$	$\frac{327,625.8}{216,233.0}$
6	14.0-14.9	0.012	2.8x10 ⁶	$\frac{1.00}{0.66}$	33,600	0.9950	$\frac{33,432.0}{22,065.12}$	$\frac{568,344.0}{375,107.0}$
7	15.0-15.9	0.0002	2.8x10 ⁶	$\frac{1.00}{0.66}$	560	3.9891	$\frac{2,233.90}{1,474.37}$	$\frac{17,871.2}{11,795.0}$
TOTAL				$\frac{1.00}{0.66}$			$\frac{58,486.74}{38,601.25}$	$\frac{1,805,007.1}{1,191,304.7}$

APPENDIX D

TABLE D-6. Estimate of the Loss of One Year-old Emerald Shiner Recruits as a Result of Assumed Entrainment Mortality at the Davis-Besse Nuclear Power Plant in 1975.¹

LENGTH CLASS (/)	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED	NUMBER OF LARVAE OF LENGTH CLASS / N _i	SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 1	ADULTS (AGE 1)	
							PER DAY	PERIOD OF CAPTURE
1	7.0- 7.9	0.0333	8x10 ⁴	1.00	2,664	0.0199	53.01	5,142.3
2	8.0- 8.9	0.0111	8x10 ⁴	1.00	888	0.0305	27.08	2,627.1
3	9.0- 9.9	0.0097	8x10 ⁴	1.00	776	0.0289	22.43	1,861.4
4	10.0-10.9	0.0068	8x10 ⁴	1.00	544	0.0447	24.32	2,018.3
5	11.0-11.9	0.0028	8x10 ⁴	1.00	224	0.1137	25.47	1,655.5
6	12.0-12.9	0.0022	8x10 ⁴	1.00	176	0.2342	41.22	2,679.2
7	13.0-13.9	0.0011	8x10 ⁴	1.00	88	0.4191	36.88	2,397.3
8	14.0-14.9	0.0005	8x10 ⁴	1.00	40	0.8849	35.40	2,300.7
9	15.0-15.9	0.0002	8x10 ⁴	1.00	16	2.6539	42.46	424.6
TOTAL				1.00			308.27	21,106.4

¹Davis-Besse Nuclear Power Plant did not operate during 1975

APPENDIX D

TABLE D-7. Estimate of the Loss of One Year-old Emerald Shiner Recruits as a Result of Entrainment Mortality at the Davis-Besse Nuclear Power Plant in 1976.

LENGTH CLASS (/)	LENGTH (mm)	MEAN DENSITY No./m ³	PLANT FLOW m ³ /day	FRACTION KILLED	NUMBER OF LARVAE OF LENGTH CLASS / N _i	SURVIVAL PROBABILITY FROM LENGTH CLASS / TO AGE 1 S _i	ADULTS (AGE 1)	
							PER DAY	PERIOD OF CAPTURE
1	9.0- 9.9	0.320	8x10 ⁴	1.00	25,600	0.0048	122.88	5,898.2
2	10.0-10.9	0.166	8x10 ⁴	1.00	13,280	0.0107	142.10	6,820.8
3	11.0-11.9	0.131	8x10 ⁴	1.00	10,480	0.0139	145.67	6,992.3
4	12.0-12.9	0.072	8x10 ⁴	1.00	5,760	0.0208	119.81	5,750.9
5	13.0-13.9	0.029	8x10 ⁴	1.00	2,320	0.0524	121.57	9,360.7
6	14.0-14.9	0.012	8x10 ⁴	1.00	960	0.9950	955.20	16,238.4
7	15.0-15.9	0.0002	8x10 ⁴	1.00	16	3.9891	63.82	510.6
TOTAL				1.00			1,671.05	51,571.9